THE

AMERICAN

JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

FIFTH SERIES

VOL. I—[WHOLE NUMBER, CCI].

WITH FOUR PLATES

NEW HAVEN, CONNECTICUT.

1921.

289670

THE TUTTLE, MOREHOUSE & TAYLOR COMPANY
NEW HAVEN

CONTENTS TO VOLUME I.

Number 1.

Number 2.

Number 3.

Number 4.

SCIENTIFIC INTELLIGENCE.

Number 5.

Number 6.

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

Art. I.—*Relations of Subjacent Igneous Invasion to Regional Metamorphism*; by Joseph Barrell.[1]

CONTENTS.

SUMMARY.

[In summary, evidence is presented (Part I) that batholithic invasions widen downward and may occur close below many rocks where they have not been suspected.

[1] This paper was written by Professor Barrell apparently in the year 1913 or 1914. He later added some marginal notes and rearranged it, but never put it in finished form. He had mentioned to me certain plans for using the material and, on the basis of those statements and the marginal notes, I have edited the manuscript. It is evident from his notes that he planned a rearrangement to include definitions given by other authorities. This I have attempted, putting in brackets all the essential parts which have been added.
Frank F. Grout.

Batholiths like those in the American Cordillera seem to come to place without crustal compression, but those of the Archean shield and those of the later Appalachian invasions are accompanied by compression. A detailed study of three or four regions shows the metamorphism to be related to the igneous invasion more than to the depth and pressure. One of the regions of deepest burial and close folding in Pennsylvania shows slight metamorphism.

II. The action of magmas, both by heating and metasomatism, is reviewed. The solutions are not meteoric in origin. The results in minerals depend on equilibria,—largely on the presence of H_2O and CO_2.

The depth of anamorphism may be small, due (1) to weakness of some rocks, (2) to invasion of batholiths. An argument for shallow depth is based on the completeness of Archean metamorphism and the salt of the ocean as a measure of erosion.

III. The features of metamorphic rocks are reviewed and interpreted as due to one or another factor. Major factors are batholithic invasion and compression. Movements of solutions, selective crystallization, lit-par-lit injection gneisses, and the alternation of injection and mashing, each leave their marks.]

PART I. REGIONAL RELATIONS.

Introduction.

The phenomena of regional metamorphism are manifested in a widespread crystallization and reconstruction of rocks, in granulation and recrystallization. Mashing and shearing compete with folding, as three distinct modes of yielding, in giving complicated structures; mashing and recrystallization lead to segregation of minerals in layers, and are manifested in a dominant foliated and banded arrangement which formerly was taken as evidence of sedimentary origin. Metamorphosed terranes pass in places into massive holocrystalline rocks which are now proved in most cases to be of intrusive igneous origin. In rare cases, however, they seem to be completely recrystallized sediments. A former interpretation which prevailed in this country until near the close of the nineteenth century regarded all these gneisses, including the granite ones, as merely the last term of metamorphism of sediments in place, especially in the

heated and softened bottoms of geosynclines. Orogenic deformation was looked upon in connection with the trapped sea waters as the agent which accomplished the work. The newer interpretations, however, regard the fluids and gases of igneous rocks as of juvenile origin, making their way for the first time toward the surface of the earth. These present views in regard to the origin of the granitic rocks and their emanations raise the problem as to how far igneous action is essential for the development of regional metamorphism. To what extent does regional metamorphism imply the invasion of deep-seated bodies of magma of regional extent, even when these give no direct evidence of their presence; or to what extent may mere crustal compression and deformation of deeply buried rocks carry forward this work?

Since, by the very terms of this question, the magmatic invasions, if they are the controlling causes of regional metamorphism, are concealed, the problem can not be directly solved. It must be attacked by inference, but the attack is none the less desirable, since it raises problems with many bearings, and directs the attention to the observation of field relations. The accumulation of these from many sources and by many minds must in the end give adjusted quantitative value to the opposing factors and lead to a better understanding of the mysterious inner earth.

The problem and the conclusions, as outlined in this article, were formulated in the mind of the writer from 1904 to 1906, and presented more or less completely to successive classes of advanced students. The points for first presentation are profound metamorphism of some large areas in New England where igneous rocks are near by, but the depth of burial slight; and the relatively small effects in a Pennsylvania region where igneous rocks are absent, but the depth of burial has been very great, and folding fully as close as in the New England region.[2]

The fact that in all the intensely metamorphosed

[2] [The degree or intensity of metamorphism is judged by the usual criteria: deformation of original structures and textures; formation of new minerals; recrystallization; shape, size, and arrangement of grains with resulting cleavage and luster; and changes in the composition of the rock. The changes that occur without notable additions were discussed by Lahee in a paper on the crystalloblastic order and mineral development in metamorphism (Jour. Geology, 22, 500, 1914), but in this paper instances are cited where the changes are more profound and result from magmatic additions.]

province of the southern Appalachians no post-Cambrian intrusives were mapped by the geologists who worked in that field, whereas much of the metamorphism was of post-Cambrian date, led the writer to hold the matter in considerable reserve, and refrain from publication. But in 1907 Keith in the Pisgah, North Carolina, folio[3] noted the undetermined age of the Whiteside granite which occupies large areas in North Carolina and Georgia, and stated that it might be as late as Carboniferous. In the geological map of North America issued in 1911, large granite areas in the southern Appalachians are mapped as post-Cambrian; and in the Ellijay, Georgia, folio,[4] 1913, La Forge and Phalen state, in regard to the small patches of younger granite on the east and the gabbro dikes cutting the Lower Cambrian on the west, that from their structural relations both are believed to be of late Paleozoic age. This increase of knowledge brings the late Paleozoic orogenic history of the southern Appalachians into closer kinship with the late Paleozoic history of New England. It was the study of the latter field, in addition to some years of experience in the Cordilleran province, which led to the development of the ideas expressed in this article. They apparently may be extended to cover the southern Appalachians, and seem to imply enough generality of application to warrant publication. Various additions have been made to utilize the contributions bearing on this subject made by others in later years.

Subjacent Igneous Invasion in Mountain Provinces.

Suess and Daly have in separate volumes broadly discussed in recent years the phenomena of batholithic invasion. Adams and Barlow, Sederholm, and others have made clear many detailed illustrations. The cumulative effect of all this work is to show the widespread occurrence of those bodies named batholiths by Suess, which he, in common with the French geologists, held to broaden downward "bis in die ewige Teufe", and which Daly classifies as subjacent igneous bodies in order to distinguish them from those clearly injected into the crust. In broad regions, these are now known to be of Paleozoic, Mesozoic, and even of Cenozoic age, extending

[3] A. Keith, U. S. Geol. Survey, Geol. Folio 147.

[4] L. LaForge and W. C. Phalen, U. S. Geol. Survey, Geol. Folio 187.

through geological time that process which operated so widely in the Archeozoic and destroyed by batholithic invasion, perhaps everywhere, the older foundations of the earth.

Harker[5] makes the valuable distinction between the character of igneous intrusion in plateau and in mountain provinces. In the first, the intrusions have not been connected with great compressive movements; in the second, they are so related, and this determines a different habit in the forms of the intrusive bodies. Harker, however, does not go into the problem of the granite gneisses and their contacts as exhibited in provinces marked by regional metamorphism. In fact, he favors Brœgger's view that the granite batholiths are nothing more than large and irregular laccoliths.

In the classification of batholiths according to the environing conditions which existed at the time of their solidification, we may draw two distinctions. First, they may have approached to within a few thousand feet of the surface of the earth, into a zone of fracture and rapid cooling, or they may have ceased their upward progress at a depth of miles, while still in the zone of flow and where their heat and their emanations would persist and affect the roof above them for at least a geological period. Those coming to rest at a depth of a few miles may become exposed in later ages by profound erosion. Those which lie deeper, if there be such, can never be recognized, except indirectly by an interpretation of their effects.

Secondly, we may divide batholiths, following the suggestion of Harker, into those whose rise has not been accompanied by regional deformation, and, on the other hand, those during whose rise great regional deformation has prevailed. To illustrate these categories: The Boulder batholith of Montana is a body whose exposed portion covers about 1100 square miles, and whose cover over broad areas consisted merely of a somewhat earlier series of extrusive andesites a few thousand feet in thickness. Some folding of the older sedimentary rocks seems to have gone on before the invasion of the batholith, but the latter shows no effects of compression. The disturbances at the time of its origin and later seem to have been essentially movements of vertical adjustment.

In New England, on the other hand, the granites are

[5] A. Harker, Natural History of Igneous Rocks, Chap. III, 1909.

associated with regional metamorphism and themselves show various stages of mashing. Some, such as those of eastern Massachusetts, are intruded into Carboniferous schists and must have reached comparatively near to the surface; others, especially many of the pre-Cambrian granites, must have solidified at profound depths, since the portions now exposed have been uncovered through many cycles of uplift and erosion.

It is especially with this group, which is illustrated in the regionally metamorphosed province of New England, and which may be called *orogenic batholiths,* that this article is planned to deal.

Underground Extension of Cordilleran Batholiths.

To estimate the part which batholithic invasion may play in regional metamorphism, it is necessary to form a conception as to the amount of broadening which they may take on with depth. The first step in observation and inference is from the nature of the margins. These in places show broad, flat or domal, or irregular roofs; in other places, contacts plunging steeply for thousands of feet. The general character, however, is a broadening with depth. Inference from the nature of the outcrops can not safely lead us very far, but it does show no evidence of a bottom, no narrowing into pipes or laccolithic form. The doming of the roof would result from the hydrostatics of the magma, without any need of a floor. Being lighter than the solid rock around it, the batholith must perforce exert an upward pressure, and a pressure greater in proportion to the thinness of the cover.

The next step downward is taken by noting the relation of cupolas to the main body. The roof is seen to be irregular, and beyond the margin satellitic stocks break up and are intersected by the erosion surface. Erosion to a greater depth would join these to the parent body, and show at farther distances a new set of satellitic stocks. The location of these latter can be recognized in places by the centers of outlying metamorphism or centers of converging dikes.

On a larger scale, small batholiths are seen to occur more or less irregularly in regions adjacent to the greater ones. A good illustration is seen in the great batholith of central Idaho and its relation to those of southwestern Montana. They transgress rocks of various Mesozoic

ages, but are younger than early or middle Tertiary. They seem, therefore, closely related in age to the Laramide revolution, their intrusion beginning in the Cretaceous and probably extending into the Eocene. The Idaho batholith is 250 miles long by 80 miles wide. The Boulder batholith outcrops 80 miles east, showing a length of 60 miles, and a width of 18. Between the two are various smaller batholiths and stocks of irregular form and distribution. Still farther east 80 to 100 miles, in the Little Belt quadrangle, occur the Castle Mountain and Crazy Mountain stocks. Thus there is an irregular dying out of surface exposures from Idaho toward central Montana. But the Little Belt region is particularly instructive in giving suggestions of a broad underground occurrence of intrusions. Numerous dikes occur, but the most striking feature is found in the south central portion of the quadrangle. Here a mountain rises to an elevation of 8200 feet, showing no igneous core, but rivalling in elevation the mountains made by the Crazy Mountain stocks and their aureole of metamorphosed sediments. This mountain, like those possessing central stocks, has on its flanks a zone of radiating dikes. The physiographic form points to a local hardening of the sedimentary formation, a zone of metamorphism which, as shown around the other stocks in the Livingston formation, is equally or even more resistant than the igneous rock in the center. The dikes, to those who seek their meaning, look inward to a hidden igneous body, like the statues of the Alhambra legend whose eyes focussed on the spot of buried treasure. Interpreting the Crazy and Castle Mountain stocks in accordance with these indications of hidden magma, as well as by their own broad metamorphic girdles, leads to the conclusion that they must widen downward, and that much of the region is underlain by a broad batholith of which only the roof-dikes and the greater cupolas show upon the surface. The irregular flexures of the Livingston formation are due to the irregular sagging and doming of the cover of a magmatic chamber now solidified. Some compression is shown, but the chief feature of the deformation is its irregular vertical warping.

To the south, in the Yellowstone National Park, Hague[6] has shown that many of the stocks are not volcanic necks and never reached the surface, and Daly[7] has presented

[6] Arnold Hague, Science, new ser., 9, 425-442, 1899.
[7] R. A. Daly, Proc. Amer. Acad. Arts and Sci., 47, 63, 1911.

the reasons for regarding these stocks as the seat of a Pliocene batholith which here may have broken through its roof. Thus there are strong inferences that regional batholithic invasion has occurred under a vast region in Idaho and western Montana, a larger portion being concealed than has become revealed by erosion.

Another line of evidence of broader character is found in the lava flows and volcanic breccias which spread over the greater part of the Cordillera. These imply the presence of widespread magma with depth as the sources of this surface material. But the study of regions of exposed batholiths shows that gravitative differentiation proceeds, granites coming to occupy the upper parts of the magma chamber and invading even the older and more basic surface materials. This is the history of the Laurentian cutting the Keewatin flows, and of many younger examples down to the Boulder batholith, whose quartz monzonite comes to metamorphose and cut the somewhat older andesites and basalts. The evidence of exposed regions suggests, therefore, that Tertiary granite should occur widely in depth under much of the Cordilleran province.

Still another line of inference, and the one of broadest character, is that founded on the geodetic evidence. Cordilleran seas occupied, through much of Paleozoic and Mesozoic times, portions of what is now one of the great plateau regions of the world. Mountain ranges were raised, and crustal warpings took place from time to time then as now, but the general average of the Cordilleran province remained near sea-level, as shown by the preservation, through these earlier eras, of sediments mostly of marine origin. The principle of isostasy requires that the subcrustal regional densities must have corresponded with this attitude, giving conditions of equilibrium.

Now, however, the geodetic observations show that a condition of regional isostasy prevails, comparable to that in other portions of the United States, notwithstanding the mountainous as well as plateau character of the province. Furthermore, there is evidence that in the Great Basin the depth of isostatic compensation is probably shallower than in any other part of the United States. This contrast of the present and the past is strongly suggestive of a thinning of the crust and a decrease in subcrustal density in the Cordilleran

province during the Cenozoic. The most probable, and perhaps the only cause, which can be assigned to explain this effect is a general rise of magma to higher levels, the heat being carried by emanations and volcanic outbreak into the roof rocks. The result would be decrease in density, because of thermal expansion as well as that expansion dependent upon the passage from the solid to the liquid state.

In accord with the evidence that the Cordilleran province has been uplifted by vertical forces, forces which may be inferred as due to intrusion, is the fault block character of the region. Mountain folding and overthrusting have not been absent, but the more dominating feature is found in the presence of gravity faults which show that large blocks of the crust have been elevated by vertical forces. The process culminates in the high and unfolded crust blocks of the Colorado plateaus, but with a few exceptions even the basin blocks have been elevated and the average elevation of the Great Basin is now probably between 4000 and 5000 feet above the sea.

Although each broader step of inference leads to a view of broader subcrustal igneous invasion, it does not prove that a universal molten sea of rock underlies the Cordillera at a moderate depth. The crust seems to possess sufficient rigidity to show that the rise of magmas never at any one time wholly broke up the foundations of the older crust. It seems to have been an intermittent process and to have gone forward on axial zones, as shown by the trend of the fault block structures.

Erosion to a depth of some miles, or even to the present sea-level, would, however, show an enormous extension of batholithic outcrops, and remind one of the broad development of the Laurentian granites. That which gives unique character to these earliest invasions is the profound depth to which erosion has penetrated, as well as a more universal development.

Batholiths of New England.

The outcrops of the pre-Cambrian are confined to restricted areas in New England, occurring especially in the anticlinorium of the Green Mountain axis and, according to the geological map of North America issued

in 1911, in smaller areas adjacent to Narragansett Bay. The Green Mountain granitic axis shows inclusions of sediments corresponding to the Grenville series, and these doubtless are an extension of the Laurentian granite gneisses as shown in Canada and the Adirondacks. The indications are that the axis once formed the floor of all New England upon which the Paleozoic sediments were laid down. The character of the Laurentian has been described by many geologists, the intrusive nature being first recognized by Lawson in 1885. The detailed descriptions of the Haliburton-Bancroft district by Adams and Barlow[8] develop two conclusions of importance in the present connection. First, the intrusions are in broad domal masses, in which movement went forward during crystallization. Second, the granites profoundly altered the adjacent sediments, and this metamorphism dies out with distance from the intrusions, the amphibolites and paragneisses of the Grenville passing into blue limestones interbedded with more clastic layers. Where exposed in New England, the Archeozoic is dominantly the Laurentian granite, and the older sediments consist of minor areas profoundly metamorphosed and injected.

Turning to the Paleozoic intrusions, an inspection of the geologic map of North America will show the large extent to which they outcrop east of the Connecticut River. Between the Connecticut and the Green Mountain axis they occur more sparingly and in smaller areas. This marks the boundary of the batholiths, and farther to the west, in the Taconic synclinorium, even dikes are rare or wanting. Dale has noted an amphibolite intrusion eight miles west of Pittsfield, Massachusetts. In the region of Franklin Furnace, New Jersey, dikes, mostly basic, volcanic necks filled with breccia, and a laccolithic intrusion of nepheline syenite occur just west of the southward extension of the pre-Cambrian axis.

The evidence is clear that the New England batholiths reach much wider development at moderate depths below the present surface. Many show domal form to their margins and between them the sediments are in many places so infiltrated with magmatic emanations and cut by pegmatite dikes as to leave no room for doubt that they are the roofs of bodies of granite. The chief struc-

[8] F. D. Adams and A. E. Barlow, Geol. Survey Canada, Mem. 6, 1910.

tural distinction between this province and the Laurentian of Canada appears to rest upon the lesser depth to which erosion has planed and the resulting lesser destruction of the batholithic roofs.

Relations in New England between Batholithic and Metamorphic Limits.

Preliminary Statement.

The regional metamorphism of New England is marked both by a thorough recrystallization of the sediments and a folding and mashing. The intrusive rocks are also involved to a greater or less extent. The generality of this relation, both for this and other regions, has caused them to be linked together in geological theory as direct cause and effect; the deformation of deep-seated rocks being regarded as the cause of their regional metamorphism. This conception developed, however, before the igneous and intrusive nature of the basal gneisses was recognized, and even yet the importance of deep-seated batholithic extension has not been considered in the theory. It is desired here to test this prevailing conception against another which would regard recrystallization as largely and directly related to batholithic heat and emanations, and the folding and mashing as a related but partly independent process, due to crustal compression, but going on most readily in the weak and recrystallizing roofs of batholithic chambers.

The Pre-Newark Floor of the Connecticut Triassic.

To test this question, let the region be considered which lies in Connecticut between the Triassic of the Connecticut Valley and the dying out of the Appalachian folds in the Hudson Valley. The crust movement at the close of the Newark sedimentation gave a regional tilt of about 20° east to the rocks of the Connecticut Valley, and a regional tilt of about 20° west and northwest to the New Jersey area. Extensive faulting also took place as a part of the movement. The western margin in Connecticut, the eastern in New Jersey, are not in general, however, fault boundaries. They are the two slopes of a geanticlinal arch upraised at the beginning of the Jurassic period. The fault movements, however, partly neutralized the effects of the tilt, so that the actual elevation of

this axis in western Connecticut is unknown. Nevertheless, the breadth and dip of the crust blocks show that the elevation was great, notwithstanding that peneplanation had ensued by the beginning of the Comanchean.

The Connecticut Valley is the foot of the eastern slope of this Jurassic anticlinorium. As a result of later base-levelling across this, on going west from the edge of the valley one passes progressively into rocks originally deeper and exposed by successive cycles of post-Newark erosion. On the edge of the Connecticut Valley, as Davis was first to note, is exposed the old Triassic floor upon which the basal Newark sediments were laid down. Here there has been no erosion since the mid-Triassic beginning of the Newark sedimentation. It is physiographically the nearest to the surface of the earth in the Appalachian revolution of any part of western Connecticut. What, then, is its character? In the northern half, two granite bosses outcrop, each about four miles in diameter. The northern especially is associated with more or less fine-grained intrusive amphibolite. The country rock is a lustrous sericite schist, becoming coarse-grained where penetrated by pegmatite dikes and dikelets. In the southern part of this border zone, the Prospect gneiss is intersected. This is a belt exposed for more than thirty miles, with an average width of two miles, and striking slightly diagonal to the contact. It consists of sheets of slightly gneissoid coarse biotite granite porphyry. The texture is highly variable, and it seems to have been intruded in successive sheets. It does not widen in passing away from the Triassic floor into what was presumably greater original depth. It appears, then, to have been a great dike intrusion, rather than a batholith. South of this occurs a dark slate, the Orange phyllite, containing quartzitic and calcareous beds. This is the least metamorphosed sedimentary formation in western Connecticut. South of this is found the Milford chlorite schist, extending to Long Island Sound. This is a hydrothermally altered series of basic sheets, strongly resembling the Keewatin chlorite schists, though of Paleozoic and probably of late Paleozoic age.

The topography of this area is in detail rugged, sheets of feldspar porphyrite (now slightly altered) having been injected into a previously mashed series of much the same composition. The older and thoroughly chloritized portions are probably only slightly older, as shown

by the similarity in composition. They show that extensive deformation and hydrothermal alteration was going forward at the time of their formation. They have the character and relations of a superficial series whose basic nature marks the first intrusion of the batholithic magmas. Such series, as seen more clearly in the Cordilleran field, accumulate as thick surface flows and breccias as the first stage in the batholithic cycle. As they thicken, injection into them takes place, as well as outpourings on the surface. If any of these are ancient surface flows and breccias, the evidence is, so far as the writer has observed, now destroyed, and it is only the latest intrusive sheets which show much of their original nature. These are thin and somewhat limited, showing in places chilled margins on both contacts. The alteration has been a hydration and pyritization accompanying and following mashing by which chlorite, serpentine, quartz, calcite, and pyrite have been developed. The pyritization proceeded along the joints of the more resistant sheets, showing that jointing persisted in the unmashed portions. Rare, thin seams of pegmatite with tourmaline are found. The assemblage of phenomena show alteration at only moderate depth.

The changes in passing from central Massachusetts to Long Island Sound along this resurrected Triassic floor show a progressive rise through the crust from the broad areas of Williamsburg granite, which Emerson regards as of Carboniferous age, to comparatively superficial rocks and possibly surface flows, presumably of the same igneous cycle as the granites to the north.

Now, the degree of deformation does not notably change. Cleavage and close folding is dominant in the southern as well as in the northern part, but the degree of metamorphism is conspicuously different. Surrounding the granites, feldspathization and pegmatization have occurred. Garnet, staurolite, and sillimanite are developed. The sediments are transformed into coarse and lustrous muscovite schists, the basic rocks into amphibolites. In the south, removed from the batholiths and presumably nearer the ancient surface, the argillites are black slates, somewhat crumpled and lustrous, but such as, if occurring in a more homogeneous formation, might have supplied slates of commercial quality. The impure limestones have apparently retained their carbonic acid in the presence of quartz and kaolin. The

basic igneous rocks have suffered hydration and have surrendered their lime to the carbonic acid which pervaded them. The degree of anamorphism appears, therefore, to be here conditioned upon depth and contiguity to batholithic masses, not upon the intensity of the deformation.

The Section across Southwestern Connecticut.

It has been shown that in passing westward from the Connecticut Valley one crosses a Jurassic anticlinorium leveled by later erosion. One transects also the structures imposed by earlier deformations, so that the actual depth at which occurred the metamorphism of the rocks of any given locality is difficult to state. It is clear, however, that the great faults which cut diagonally across the Connecticut Valley at Meriden largely die out on entering the western metamorphic province. This is shown by the moderate offsets of the western margin as compared to the great offsets and repetitions of the strata in the middle of the valley. Doubtless distributive faulting in the western province occurs and some greater faults may be concealed by the complicated structures. The Pomperaug Valley, holding Triassic strata in the midst of the anticlinorium, shows that it is by no means a single great structural arch. Nevertheless, the regional dip of the Triassic floor gives strong suggestions that on passing west from New Haven to Bridgeport or Derby one goes progressively into regions once deeper in the crust. It is as if the railroads were inclines at slopes of 5°, 10°, or 15° leading from the upper world downward into the abyss. The exposures are best on the New Haven-Derby trolley line. What, then, are the changes to be observed in the nature of the rocks?

At the eastern contact, the least altered sheets of porphyrite are found and quartz infiltrations are rare. One to two miles west, the cleavage is much more pronounced and uniform. Considerable silicification is present and quartz lenses occur in discontinuous strings, having deformed the chlorite schists by the power of their crystal growth. One passes then into the Orange phyllite, a soft black crumpled slate. Some three miles farther west, the first sheets of the biotite granite porphyry appear, interbedded vertically in the highly foliated sediments. Within a few hundred feet of the

first thick sheet, quartz infiltrations become noticeable, then fine-grained garnets enveloped in muscovite. Within a hundred feet the sediments become transformed and at the contact are lustrous but fine-grained schists. In between the granite sheets, the texture of the schists becomes coarse and sparkling. Still farther northwest, sheets of granite and pegmatite become more abundant, the schist becomes feldspathized, crumpled, and of maximum coarseness, cyanite and garnet become abundant, the proportion of magma increases, and the rocks pass finally into truly igneous masses. In the region of Danbury the granite gneisses envelop and intrude the Stockbridge limestone, and it is found to be transformed into a coarse white friable marble.

The beginning of the intense anamorphism on this section is clearly a contact effect of the first granite sheets, here with vertical attitude. Beyond, they show evidences of being part of an injected and intensely altered batholithic roof. The metamorphism, then, is here primarily related to the presence of magmas, but is secondarily related to depth. Deformation is the adventitious factor which has affected all the section and produced cleavage with hydration in the upper and cooler portions, cleavage with dehydration in those portions which are deeper, hotter, and invaded by magmatic emanations.

The Section across Northwestern Connecticut.

The writer has made a study of the geologic section on the northern state line of Connecticut from the Green Mountain anticlinorium, here represented by the southern Berkshire Hills, westward across the Taconic synclinorium into New York State. The Laurentian Becket gneiss, with its included metasediments, and the Lower Cambrian Dalton schist outcrop in the anticlinorium. The rocks are overturned and overthrust upon the Stockbridge marble of Cambro-Ordovician age. This outcrops in the picturesque Housatonic Valley, here some eight miles in breadth and marking the structural limb between anticlinorium and synclinorium. The axis of the latter holds synclines of the resistant Berkshire schist, of upper Ordovician age. The structures throughout are intensely deformed by minor and major folds and by mashing. The foliation planes are in general inclined eastward at a dip of about 30°, showing an intense regional overthrusting.

The metamorphism of the Paleozoic sediments is intense. The Lower Cambrian sediments, originally feldspathic muds, have been transformed into lustrous muscovite schists, microcline gneisses, and quartzites. The schists are closely crumpled, and show segregation lenses of quartz, holding needles of tourmaline. The Cambro-Ordovician limestone has become a white or mottled marble holding mica and tremolite. Quartzitic bands in places include needles of tourmaline. The Berkshire schist in the eastern outcrops shows coarse crystallization and the development of garnet and staurolite. In the axis of the synclinorium, however, the metamorphism of this rock dies out rapidly, and it turns to a grayish or greenish sericite schist. In New York State it passes gradually into the dark Hudson River slates.

It would seem that here the severity of the deformation is roughly in accord with the degree of metamorphism and is a sufficient explanation of the facts without invoking the aid of magmatic heat or emanations. Closer observation shows, however, a lack of exact accord between the local degree of deformation and the local degree of crystallization. The small synclines of Berkshire schist in the middle of the limestone valley show strong metamorphism even where not intensely deformed. The pinched axis of the syncline, although of the same stratigraphic level, shows a lesser degree of metamorphism. The limestone beds, even where flat-lying and showing the bedding fairly undisturbed, are nevertheless transformed into coarse marbles. The rocks of the valley have, however, been deeply buried beneath overthrust masses so that the greater depth at which they were deformed must have been a contributory factor in the metamorphism.

Turning to another side of the problem, what is the evidence or lack of evidence that batholithic intrusions may lie below? The nearest Paleozoic granites, as mapped by Hobbs,[9] lie on the axis of the anticlinorium some twelve miles south of the Connecticut-Massachusetts line. None are known in the synclinorium. Direct evidence is therefore lacking. The indirect evidence is as follows: The Lower Cambrian Dalton schists overlie the Archean complex and outcrop in anticlines within the limestone valley. They vary from muscovite schists to

[9] W. H. Hobbs, in Preliminary geological map of Connecticut, by H. E. Gregory and H. H. Robinson, Conn. Geol. Nat. Hist. Survey, Bull. 7, 1906.

feldspathic quartzites. The schists show many segregation seams and lenses of quartz and feldspar, the quartz holding needles of tourmaline. The boron and fluorine which enter into tourmaline are elements not found in clastic sediments. They are commonly regarded as the evidences of pneumatolysis, but if so, they have the capacity to rise for great distances through metamorphic zones before entering into crystallization as tourmaline. It is well known that tourmaline tends to crystallize, especially in siliceous formations. Apparently, then, the volatile constituents have come as gases from some depth beneath in the Archean complex. That the boron and fluorine have shown a capacity to rise is most clearly shown in a quartzite member within the Stockbridge marble. At Ashley Falls, Massachusetts, the joints in this member show the development of tourmaline crystals in their walls, arranged across the bedding planes. The tourmaline is a replacement mineral lining the cross-cutting joints and developed at the expense of preëxisting biotite. In the Dalton schist, the development along the foliation planes conceals this kind of evidence of introduction, but the pegmatitic character of the lenses gives support to such a view.

Of course it is possible to discount the value of this evidence based upon tourmaline, and to cite the existence of fluorite deposits in regions free from any signs of igneous activity. But it is thought that the evidence given in the first part of this article on the widespread nature of subjacent igneous bodies, tends to support the view that where tourmaline is abundantly present, magmatic emanations were passing through at the time of its formation and supplied the volatile elements necessary for its development.

Another line of evidence is found in extensive infiltrations of silica which have developed, in the Stockbridge marble, reefs of malacolite, tremolite, and quartz, over a distance of eight miles between Falls Village, Connecticut, and Sheffield, Massachusetts. Several varieties and stages of the action may be noted. Reefs of rugged rocks show that, first, an infiltration of siliceous waters deposited quartz in veins. Then an increase in temperature occurred, the waters attacked the lime and magnesia, and coarse-grained tremolite replacements occurred. The reaction did not occur wholly in place, however, since the materials were taken into solution and deposited in veins

showing all gradations from quartz to pure tremolite. The tremolite veins in places cut the older vein quartz and give clear evidence of the carrying of tremolite in solution.

Between Ashley Falls and Falls Village another phase may be seen. Tough, massive reefs of white pyroxene rock, malacolite, are found, with granitic grain and in some places clearly developed by infiltration, not by the mere alteration of an impure marble. The reefs occur in certain local areas and are not restricted to a definite horizon in the marble. The large size and unbroken character of the crystals, as well as the presence of pyroxene rather than amphibole, ally these occurrences with the phenomena of igneous contact action, and show a development after the regional mashing. In general, these reefs are surprisingly free from the minerals usually associated with igneous emanations. Only rarely is pyrite or chalcopyrite found, and in only one locality near the eastern margin of the limestone is tourmaline associated. Here, near the head of Whiting River, large crystals of feldspar and phlogopite and smaller ones of tourmaline occur with malacolite. Thus this evidence, while indicative of rising waters, does not clearly show those waters to have been magmatic.

Lack of Metamorphism in the Pennsylvania Folds.

The valley in Pennsylvania between the pre-Cambrian and Silurian outcrops corresponds in structural position to the valley in western New England which has just been described. It is a region of close folding, the folds becoming open farther west in the state. The limestones of this eastern belt have been crumpled into folds, many of which are but some tens of feet in radius. In other places, extensive overturning into recumbent folds has taken place. The argillites above have been mashed into slates holding much of commercial quality. The writer has recently assembled the evidence to show that a great depth of cover has been removed from this region,[10] but the nature of the structures alone serves to make it clear that they originated at considerable depth. It is regarded as a tract of great crustal shortening,[11] and the

[10] Joseph Barrell, The Upper Devonian delta of the Appalachian geosyncline, this Journal (4), 36, 429-472, 1913; 37, 87-109, 225-253, 1914.
[11] R. T. Chamberlin, Jour. Geology, 18, 228-251, 1910.

depth at which took place the folding of the rocks now exposed was certainly in places several miles, even allowing for erosion accompanying folding. Chamberlin's restoration, not allowing for erosion, shows a depth of four and a half miles as a maximum on the west, and six miles as a maximum on the east. In depth of burial and intensity of deformation, this region must therefore be regarded as having been subjected to conditions as severe as those of western New England. No evidences of Paleozoic igneous intrusion younger than the Cambrian are found in the region, the nearest of such intrusions being some pegmatite dikes in the Philadelphia region.

What, then, is the degree of regional metamorphism as compared to western New England? It is found in answer to be insignificant. The effects have been a reduction of porosity and a partial elimination of the combined water from the argillaceous sediments. At the base are limited thicknesses of Lower Cambrian quartzite with some beds of hydromica slate. Above this, the Cambro-Ordovician limestone shows no degree of alteration. The upper Ordovician slates are dark and rather dull in luster. Under the microscope they show a grain beneath a tenth of a millimeter in diameter. Sericite giving aggregate polarization is the most abundant mineral, but kaolin also occurs.[12] There is thus seen to be a profound difference from those coarse white marbles and garnet-staurolite mica schists which occur in the same structural belt in western New England.

Since the depth and deformation have been great in both cases, the difference can logically be ascribed only to a lack in the Pennsylvania region of heat and crystallizing solutions. This in turn suggests what is in accord with the other lines of evidence, that magmas have underlain the one region at moderate depth, and have been absent from the other.

[Daly[13] reasons similarly from his work in British Columbia, and cites authorities for other localities showing that deep burial has produced metamorphism that is only partial or nil.]

(To be continued)

[12] T. N. Dale, U. S. Geol. Survey, Bull. 275, pp. 75-85, 1906.
[13] R. A. Daly, Bull. Geol. Soc. America, 28, 405, 1917.

ART. II.—*Note on Augite from Vesuvius and Etna;* by HENRY S. WASHINGTON and H. E. MERWIN.

The problem of the constitution of the pyroxenes that contain alumina and ferric oxide—the augites—is one of the most puzzling and, in some respects, one of the most important that are presented by the rock-forming minerals. In an effort to aid its solution, I have made during the last few years a number of analyses of typical augites from Italian volcanoes, in the lavas of which augite is one of the most constant and most characteristic minerals. The study of these is not yet complete, and several more analyses remain to be made. But having recently completed two analyses of augite from Vesuvius and Etna, of which Dr. H. E. Merwin has determined the optical and crystallographic data, it seems to be advisable to publish the results as a slight contribution toward our knowledge of this important group of minerals. This seems to be the more justified as, notwithstanding that the species was based first on the crystals from these two volcanoes, we have as yet no satisfactory or modern analyses of them.

AUGITE FROM VESUVIUS.

Vesuvius has long been noted for its pyroxenes. Beautiful diopsides are found in many of the ejected blocks of Somma, and loose crystals of augite are among the products of many of its eruptions. The crystals studied here were obtained from the bottom of the crater, in part by me in June, 1914, and in part by Dr. A. Malladra, Director of the Osservatorio Vesuviano, during the same spring. For his kindness in sending me the material for study I would express my sincere thanks.

Occurrence.—The crystals are found, either loose, and entirely or almost entirely free of scoria, as at many other volcanoes; or as phenocrysts in a highly vesicular leucite tephrite, which was being ejected in small amount from the orifice at the bottom of the funnel during my visit to it.[1]

The crystals are mostly of the usual, well-known, simple forms, such as are figured by Dana[2] and in ...t text-

[1] A. Malladra, Rend. Acad. Sci. Napoli, November, 1914; ...gton and Day, Bull. Geol. Soc. Amer., 26, 375, 1915.

[2] Dana, System, Figs. 16, 17, and 18, page 354, 1892.

books of mineralogy. The faces present are: *a*(100), *b*(010), *m*(110), and *s*($\bar{1}$11). A small proportion are twinned, forming the common contact twins, with twinning plane *a*(100). They vary, in general, from 3 to 5 mm. in length (parallel to the vertical axis), though some attain lengths of one centimeter or more. The thickness is from one-half to two-thirds of the length, and there is usually a slight tabular development parallel to *a*(100). The faces are fairly smooth and bright, much brighter than those of the Stromboli augites described in a previous paper,[3] and the edges are sharp. There is but little scoria adherent to the loose crystals, but microscopical examination of the powdered material revealed the presence of small amounts of inclusions of glass and crystalline matter (magnetite, leucite, and feldspar).

Physical data.—Of a dozen crystals studied, four had sets of faces that were sufficiently good for approximate measurements (by Merwin). These indicate the probability that crystallographically diopside does not represent augite. The measurements were as follows:

$m \wedge m$ (110) $\wedge$ (1$\bar{1}$0)=92°0′-93°57′; mean= 92°56′ 4 measurements.
$s \wedge \bar{s}$ ($\bar{1}$11) $\wedge$ ($\bar{1}\bar{1}$1)=61°20′-59°50′; mean= 60°36′ 8 measurements.

For diopside the values are:

$$m \wedge m = 92°50', \ s \wedge \bar{s} = 59°11'.$$

Measurements of ϕ and ρ for four pyramid faces, *s*, gave values of 24°23′-25°5′ and 34°1′-33°15′, respectively, as compared with 25°7′ and 33°4′ for diopside.

Speaking of the pyroxenes as a group, Dana long ago pointed out:[4] "It is noteworthy that the angles vary but little even for a wide variation in composition." While this is quite true, yet since that time, with more exact means of measurements and of chemical analysis, a more systematic study of the relations of the physical and chemical properties, and for other reasons, we are beginning to appreciate more than we did thirty years ago the probable importance of even small variations.

An optical examination showed that the Vesuvius augites studied are variable in composition. The general color ' slightly yellowish gray, and there is little indi-

[3] Kozu and Washington, this Journal, 45, 463, 1918.
[4] Dana, System, 363, 1892.

cation of zonal structure. There is little if any pleochroism. The index β varies from 1.700 to 1.711. The extinction angle is large, as usual, about 45°, but no exact measurements were made, because of the variability in composition and the consequent indeterminateness of the data.

The specific gravity of the crystal fragments used for the analysis was found to be 3.242 referred to water at 23°. This low result is probably to be ascribed to the presence of the glass inclusions.

Chemical composition.—For my analysis some of the cleanest loose crystals were selected, and, in order to obtain sufficient material, to these were added crystals obtained from specimens of the scoria from about the orifice. Great care was taken to free the crystal fragments from adherent scoria, and the analysis was made on what was probably as pure material as could be obtained from this source. It was, however, not practicable to obtain material entirely free from the small inclusions of glass, etc., and the analysis, therefore, does not represent an entirely pure augite substance. In spite of this defect, however, it is thought best to publish it, as a slight contribution to our knowledge of the Vesuvian augites, and as illustrative of the dangers, in the form of included foreign matter, that may lurk in the chemical study of many minerals. The presence of the inclusions is also of interest in view of the very close correspondence in chemical composition between these augites and a pyroxenite published by Lacroix, to be mentioned later.

TABLE I.

Analyses of Augites of Vesuvius.

	1	2	3	4
SiO_2	47.60	46.95	46.42	47.90
Al_2O_3	6.01	6.75	9.14	6.58
Fe_2O_3	3.17	4.47	5.03	1.52
FeO	4.59	4.09	4.87	3.33
MgO	14.43	16.04	13.19	14.20
CaO	21.52	19.02	20.86	22.51
Na_2O	0.70	n.d.	n.d.	1.14
K_2O	0.76	n.d.	n.d.	0.38
H_2O+	0.08	n.d.	n.d.	0.62
TiO_2	1.52	n.d.	n.d.	1.49
P_2O_5	n.d.	n.d.	n.d.	0.70
MnO	0.13	n.d.	0.14	n.d.
SrO	none	n.d.	n.d.	n.d.
	100.51	100.32	99.65	100.39*

* Including F = 0.02

1. Augite, Crater of Vesuvius, June, 1914. Washington analyst.
2. Augite, Monte Somma. Doelter analyst. Tschermak's Min. Petr. Mitth., 283, 1877.
3. Augite, Vesuvius. Casoria, ref. Zs. Kryst., 42, 881, 1907.
4. Pyroxenite, Monte Somma. Pisani analyst. Lacroix, C. R. 165, 209, 1917.

Earlier analyses.—The earlier analyses of Vesuvian augites, collected by Dana, Hintze, and Doelter, and most completely by Zambonini,[5] are very unsatisfactory, either because of their early dates, or because of their incompleteness. However, two of them, which seem to be somewhat less inferior than the others, are given in Table I. While these older analyses show the general characters of augite, yet they all are seriously defective in that titanium dioxide and the alkalies are not determined in any of them, although it is clear from my analysis, and from our knowledge of augites elsewhere, that these constituents are present in distinctly appreciable amounts. The high alumina shown by them is due to the presence of titanium dioxide. Furthermore, the iron oxides are not separated in many of them. Lacroix has called attention[6] to these serious defects in all the existing analyses of pyroxenes of Vesuvius, and I can only join with him in urging the need for better analyses of this mineral group from Vesuvius and from other localities, and, incidentally, call attention to the general inferiority of the great majority of the analyses of pyroxenes, especially as regards the fundamental points of selection of pure material, and accuracy and completeness of the analyses.

The publication of analyses of such inferior quality is to be deplored, as leading possibly to seriously incorrect generalizations at the hands of those who accept blindly and without critical judgment any analysis that is offered them. One of the striking features in the study of the chemistry of minerals and rocks is the complacency with which such inferior work is accepted and published. Much of it is based on impure material, often not ascertainedly so, carried out by inexperienced analysts, by poor methods, or with impure reagents; and yet it is accepted in good faith by both analyst and author. This state of affairs has done much—much more than is generally thought—to hinder the progress of our knowledge of the chemistry of minerals.

[5] F. Zambonini, Mineralogia Vesuviana, 151, 1910.
[6] A. Lacroix, C. R., 165, 211, 1917.

Comparison with pyroxenite.—It is not necessary here to discuss my analysis of the Vesuvius augite, partly because of its being based on impure material, and partly because it will be discussed later, when the series of Italian augites is more nearly complete. Attention must, however, be called to the very remarkable correspondence between it and an analysis by Pisani of a pyroxenite of Monte Somma, published by Lacroix, which is given in column 4 of Table I. Lacroix does not describe this rock in detail, but it would appear to be holocrystalline and composed almost entirely of pyroxene. It is a somewhat noteworthy example of the possibility of diverse crystallization of a part of a magma, either as a monomineralic or almost monomineralic, granular rock, or as well-formed crystals of a definite mineral.

Lacroix mentions and gives analyses of several types of the pyroxenite, all of which are more or less closely related chemically. It occurs, according to him,[7] as homoeogenic rocks, that is, "granular forms, not only of the flows, but also of the differentiated portions of the same magma which have not necessarily reached the surface." Such homoeogenic rocks are assumedly of abyssal origin and, if the general theories of gravitative adjustment of Daly and Bowen are correct, they would be expected to have come up, or been carried up, as broken-off blocks, from very deep down in the volcanic mass. My augite crystals, on the other hand, occur, as has been said, in the light scorias that form the uppermost scum or froth of the ascending magma. This would indicate that, in this case at least, separation by gravity has not been carried to completeness. That this is also true elsewhere is indicated by the occurrence of such augite crystals (almost always of the same crystal form) at other volcanoes, such as Stromboli, Etna, and the Alban volcano. Indeed, they are rather common at many volcanoes, and similarly crystals of cossyrite and kaersutite (sodic hornblende) are met with as such loose crystals at Pantelleria and Linosa, to speak only of Italian volcanoes.

But the incompleteness of such a separative process is not to be wondered at, considering the convection currents in, and the presumably violent movements of, the upward-welling mass of magma, as well as the presence of gas, whose bubbles would act like those in a glass of cham-

[7] A. Lacroix, C. R., 165, 205, 1917.

pagne to keep up a dry raisin, which would otherwise sink. ("*Forsan et haec olim meminisse juvabit.*")

The interesting point is that, with portions of the magma of almost identical composition, we get, in the one case, a typically granular rock, and in the other, well-formed, loose crystals. We have, unfortunately, no detailed petrographical description of Lacroix's pyroxenites. Of some of them he says (page 210) that they are composed of "a little leucite filling the interspaces of plates of biotite which surround *automorphic* crystals of augite or inclose them poikilitically." Of the most pyroxenic type, that of which an analysis has been cited, nothing is said as to the form of the augites; but their being spoken of as granular ("grenues") leads one to think that the augites are xenomorphic. We know many pyroxenites from elsewhere of this granitoid type of texture and, so far as my experience of them goes, they do not show evidence of being built around automorphic and euhedral crystal cores; though conceivably evidence of such an origin may well have been obliterated in the process of growth, if this were not zonal.

It will be evident that pyroxenites of the first type of Lacroix, with automorphic augites, would be quite in harmony with Bowen's theory of the settling of the heavy crystals in a magma.[8] Bowen studied the sinking of olivine and pyroxene crystals, and the rising of those of tridymite, in artificial melts, and the striking way in which the first two sank and the third rose was sufficient proof of the actuality of the phenomenon and the relative densities of crystal and liquid. So far as I know, we have few data, at least exact data, on the densities of liquid lavas, but the point arises as to whether the augite crystals are really heavier than the liquid in which they occurred.

The density of the augite crystals was determined as 3.242 at 23°. The average density of the solid leucite tephrite of Vesuvius[9] may be taken as about 2.8, while

[8] N. L. Bowen, this Journal, 39, 175, 1915. The sinking of crystals of feldspar and their accumulation at the bottom of flows of obsidian were observed by Von Buch (Geogn. Beschr. Canar. Ins., 229, 1825), who mentions experiments made by a M. de Drée, in which feldspar crystals settled to the bottom of a crucible. The matter is discussed by C. Darwin, about 1844 (Geological Observations, 2d ed., 132-140, 1891), who attempts thus to account for the differentiation of trachyte and basalt.

[9] Cf. Roth, Abh. Berl. Akad. Wiss., 1877, 13; and Zirkel, Lehrb. Petrog., 3, 19, 1894. Roth gives the average as 2.77.

vom Rath[10] gives the values 2.512 and 2.592 as the densities of the glassy crusts of Vesuvian bombs of 1872, and Lagorio[11] 2.319 as that of a Vesuvius obsidian. We may therefore provisionally accept a density of about 2.5 for the Vesuvius glass. As to the liquid lava, we have no data; but, assuming a density of 2.8 for the solid lava, we may conclude from the discussion of Daly[12] based on Mellard Reade's and Barus' data as to expansion, that the molten lava would have a density of about 2.35. This does not take into account the presence of dissolved gases, which would unquestionably lower the density, and at the same time decrease the viscosity, very materially. It is clearly evident, therefore, that augite crystals, placed in such a leucite tephrite magma, would be much more dense than the magma, and would tend to sink, though the actual sinking of many of them would be more or less prevented by movements in the liquid, and by the possible presence of attached gas bubbles in the upper portions of the mass. Anyone who has made mineral separations with heavy liquids will appreciate the possibilities of disturbance of a "theoretically" perfect separation, adherent particles of the lighter minerals here replacing the gas bubbles of the magma.

But the occurrence of masses of rock of granitic texture, without euhedral crystals, or crystals formed freely in the body of the liquid, of the same composition as such crystals formed in what must have been a very similar magma and at the same volcano, seems to demand the recognition of some other factor than gravity, or at least one in addition to that of gravity.

This is not the place to enter into a discussion of the various kinds or causes of differentiation that have been suggested, but I must recall the case of Shonkin Sag and the explanation of its differentiation by fractional crystallization advanced by the late Prof. Pirsson, which, it seems to me, Daly has not adequately met[13] by an appeal to gravitative differentiation. Pirsson and I held much the same views on these matters, and I feel inclined to revive a theory put forward many years ago,[14] chiefly

[10] Vom Rath, Z. deutsch geol. Ges., **25**, 240, 1873.

[11] Lagorio, Tscherm. Min. petr. Mitth., 8, 475, 1887.

[12] R. A. Daly, this Journal, **15**, 277, 1903.

[13] L. V. Pirsson, this Journal, **11**, 12, 1901; U. S. Geol. Surv., Bull. **237**, 188, 1905. Cf. Daly, Igneous Rocks and their Origin, 223, 238, 1914.

[14] Washington, Bull. Geol. Soc. Amer., **11**, 409, 414, 1900; Jour. Geol., **9**, 663, 1901.

to account for the different types of laccolithic differentiation. This is based on fractional crystallization, perhaps aided by convection currents, as Pirsson supposed, the crystallization beginning at the rough walls, and the crystals of this portion (in the present case monomineralic) interfering with each other so as to produce a granitoid textured rock. Crystallization of free floating crystals (therefore euhedral) in the magma could, and probably would, also go on simultaneously. The process is analogous to the slow freezing of a bottle of salt solution, which begins at the walls, so that clear ice forms above, at the sides, and at the bottom, leaving finally a central core of highly concentrated solution. With the more complex rock magmas the process would be conceivably more complex than this, but the same general principles would seem to apply. Unquestionably, the influence of gravity might or would be felt, especially on the loose floating crystals, but this would probably have less or no effect on the wall accumulations. The process is analogous to Daly's chilled border concept, but differs from this in that, according to Pirsson's and my hypothesis, the border crystallization product does not represent the original magma, as conceived by Daly, but would be an "extreme pole of differentation."

On such a hypothesis the formation, either simultaneous or successive, of a granular pyroxenite, composed of closely packed and adherent, anhedral crystals, and free-floating, euhedral crystals, is readily understandable; more readily thus, it seems to me, than on a hypothesis based purely on the influence of gravity. It also serves to explain, as that of gravity does not, such examples of vertical, tubular differentiation as those of Magnet Cove and Mount Johnston, Quebec, which are impliedly regarded by Suess[15] as analogous to "piping" in a steel ingot.

But we are getting far away from our little augite crystals. Let us pass on to those of a near-by volcano, Etna.

Augite of Monti Rossi, Etna.

The loose crystals of augite that are found in abundance in the ashes and tuffs of Monti Rossi, formed by the eruption of 1669, and elsewhere around Etna, would

[15] Suess, The Face of the Earth, **4**, 559, 1909. Cf. H. S. Washington, Jour. Geol., **9**, 607, 1901; F. D. Adams, Jour. Geol., **11**, 254, 1903.

seem to have been among the first augites to be studied. They were described as early as 1783 by Romé de L'Isle, a few years later by Dolomieu (1788), and by Spallanzani about 1792. It may be of historic interest to cite here Spallanzani's analysis, which seems to have been the first, or among the first, of the analyses of these augites.[16] He found: "free silica 34.5, lime 18.7, iron 7.6, alumina 12.4, magnesia 11.0, sum 84.2" It will be seen that, imperfect as the analysis is from the modern standpoint, Spallanzani determined the presence of all the most essential constituents, and approximately in their relative order of abundance.

Physical characters.—The augite crystals examined were obtained in July, 1914, by Dr. Day and me in the ashes of the western summit of Monti Rossi, near Nicolosi. Though they do not appear to be as abundant as they were in Spallanzani's day, yet a handful was readily collected in half an hour.

The habit is the usual one, like that of the crystals of Vesuvius and Stromboli, though they are, on the whole, somewhat smaller, and with a decidedly greater tendency to prismatic development, some of them being three times as long as thick. They are bounded by the planes $a(100)$, $b(010)$, $m(110)$, and $s(\bar{1}11)$. The ordinary contact twins (twinning plane $a(100)$) seem to be rarer than at Vesuvius or Stromboli. They are jet black, and the faces are lustrous, much brighter than those of the Vesuvius crystals, though close examination shows that they are not flat planes, but are as if the crystals were cracked, so that they do not give good reflections for the goniometer. For this reason no crystallographic measurements were made.

In powder or particles under the microscope they are of a greenish gray color, without pronounced pleochroism. The refractive index β varied from 1.710 to 1.715; the highest value of γ was 1.735, and the lowest of α was 1.702. Thus the chemical analysis is probably very closely represented by the values: α=1.704, β=1.711, γ=1.732.

The extinction angle is high, but was not determined, as the cleavage is poor and it was not thought worth while to grind a section parallel to $b(010)$.

[16] Spallanzani, Viaggi alle due Sicilie, (1) Chap. 7, (page 172 of Milan edition, 1825). In a (somewhat pathetic) note referring to the low summation he says: "It must be noted that, apart from the almost unavoidable loss in manipulation, and that of the moisture present in the schorls, the lime is here deprived of the acid with which it was originally provided (combined)."

The specific gravity of the crystal fragments used for the analysis, determined with a pycnometer, was 3.373 referred to water at 22°.

Chemical composition.—The loose crystals appear to be very pure, except for patches of a siliceous material (which was readily removed by dilute hydrofluoric acid). Small grains of yellow olivine project from the surfaces, but they are not found in the interior of the crystals. After crushing a batch of crystals to small fragments for analysis, all these olivine particles were carefully removed by repeated search under a binocular, and the material used for analysis is confidently believed to have been free from them. The crystals, however, contain a small amount of minute inclusions of magnetite, which it was impracticable to remove entirely. Treatment with a magnet of about 0.6 g. of the powder analyzed showed that this was present to the extent of 3.94 per cent, and in column 2 of Table II the analysis is corrected for 4 per cent of magnetite.

TABLE II.

	1	2	3	4
SiO_2	47.89	50.09	47.63	47.38
Al_2O_3	3.55	3.71	6.74	5.52
Fe_2O_3	4.17	1.47	n.d.	5.52
FeO	5.98	4.96	11.39	7.89
MgO	13.40	14.01	12.90	15.26
CaO	21.49	22.48	20.87	19.10
Na_2O	0.70	0.73	n.d.	n.d.
K_2O	0.01	0.01	n.d.	n.d.
H_2O+	0.21	0.22	0.29	0.43
TiO_2	2.02	2.11	n.d.	n.d.
MnO	0.20	0.21	0.21	0.10
	99.62	100.00	100.03	99.53
Sp. gr.	3.373		2.886	2.935

1. Augite, Monti Rossi, Etna. Washington analyst.
2. Same, corrected for 4 per cent of magnetite.
3. Augite, Monti Rossi, Etna. S. van Waltershausen analyst. Der Etna, 2, 490, 1880. (First published in 1853).
4. Augite, Monti Rossi, Etna. Rammelsberg analyst. Pogg. Ann., 103, 436, 1858.

Only five or six published analyses of these augites are to be found, and all suffer from the same defects that were pointed out in the case of the Vesuvian augite, that is, non-determination of titanium and alkalies, and, in many, non-separation of the iron oxides.

Discussion.—Any extended discussion of my analysis is unnecessary here, and will be reserved for a future

occasion, in connection with those of other Italian augites. It may, however, be of interest to give the composition of the Etna augite in terms of the usual molecules, which is as follows (No. 1):

	1	2
$CaMgSi_2O_6$	70.0	80.1
$CaFeSi_2O_6$	16.5	
$CaSiO_3$	1.5	none
$(Mg,Fe)SiO_3$	none	7.5
$(Mg,Fe)Al_2SiO_6$	7.0	7.0
$Na(Fe,Al)Si_2O_6$	5.0	5.4

It will be seen that the Etna augite (1) is composed very largely of diopside and hedenbergite molecules, with a little wollastonite and acmite, and a small amount of the aluminous Tschermak molecule. In general it much resembles the augite (2) of Stromboli,[17] though this carries somewhat less of the diopside molecule, and considerable hypersthene instead of wollastonite. The respective refractive indices are as follows:

Augite, Etna $\alpha = 1.704$, $\beta = 1.711$, $\gamma = 1.735$
Augite, Stromboli, $\alpha = 1.693$, $\beta = 1.699$, $\gamma = 1.719$

This is not the place to discuss the differences, but it may be mentioned that the higher indices of the Etna augite are to be connected with its higher wollastonite and titanium content, which seem to more than counterbalance the higher ferrous oxide of the Stromboli augite. The Stromboli augite, furthermore, is slightly higher in magnesia, which would tend to lower the refractive index. On the whole, it may be said that the chemical and optical data for both of these augites are quite in accord, and bear out observations made on the pyroxene molecules generally.

Geophysical Laboratory,
Carnegie Institution of Washington,
July, 1920.

[17] Kozu and Washington, this Journal, 45, 468, 1918.

Art III.—*Chionophila Benth. A Morphological Study;* by Theo. Holm. (With 15 figures, drawn from nature by the author.)

The genus Chionophila Benth. is a member of the tribe Cheloneae, and its nearest allies in North America are Chelone and Pentstemon; as distinguishing characters Gray, Bentham and Hooker consider the structure of the calyx, corolla and fruit as the most important. The calyx being funnelform, obtusely five-lobed in Chionophila, deeply five-parted in the two other genera; the corolla being densely bearded at the base of the lower lip in Chionophila, while in Pentstemon this structure recurs only in certain species: P. barbatus Nutt., P. laevigatus Soland., P. pubescens Soland., and a few others; moreover the capsule being septicidally dehiscent in Chelone and Pentstemon, but at first loculicidal in Chionophila; in the last of these the capsule is enclosed in the marcescent calyx and corolla, while it is free in the others; also the seeds are different, being rather large, oblong, with a very loose, reticulated outer coat in Chionophila, winged in Chelone, and angulated, but marginless in Pentstemon. Very little, however, is said about the habit of Chionophila: Herba perennis, humilis, caespitosa, glabra is the characterization offered by Bentham and Hooker; a dwarf perennial, glabrous or nearly so is all, that Gray has to say.

At the time of Bentham and Gray the genus was supposed to be monotypic, but since then a second species has been proposed by Professor L. F. Henderson[1] C. Tweedyi, by Canby and Rose referred to Pentstemon, P. Tweedyi. However this second species differs from C. Jamesii Benth. according to Professor Henderson, by the corolla being quite saccate at base dorsally, thus causing the corolla to be turned aside at quite a strong angle with the axis of the inflorescence, beside by the calyx being short and more lobed, and the lower lip of the corolla being merely papillose. Professor Henderson found this new species in open, loose soil at the bases of mountains in Idaho. C. Jamesii, on the other hand, is a member of the high alpine flora of the Rocky Mountains of Colorado and Wyoming.

[1] Henderson, L. F. New Plants from Idaho and from other localities of the North West. (Bull. Torr. Bot. Club, vol. 27, 1900, p. 352.)

[2] Canby and Rose in Bot. Gazette, vol. 1ύ, 1896, p. 67.

Recently C. Tweedyi has been raised to generic rank, receiving the unfortunate name "Pentstemoniopsis,"[3] for as will be shown in the subsequent pages, the plant is undoubtedly just as close an ally of Chionophila as of Pentstemon; moreover the frequent use of making generic names by adding "opsis" has resulted in names of too great length, and sometimes also in such terrific combinations as: Saxifragopsis, Stellariopsis, Bombacopsis etc.

Now with respect to Chionophila Jamesii the plant is not caespitose, but stoloniferous, and the shoot above ground shows very plainly the structure of a typical monopodium. There is a rosette of leaves, and generally only one flower-bearing stem, which is axillary. In the center of the rosette is a bud, vegetative, which terminates the shoot, and the flower-bearing stem is always axillary, proceeding from near the base of the shoot, from the axil of one of the basal leaves. The leaves are opposite with long sheaths, and the accompanying diagram (fig. 1) shows the structure, which is the commonest met with. Four pairs of leaves constitute the rosette, $L.^1$—$L.^4$; of these $L.^4$ enclose a vegetative bud, which will develop a new rosette in the coming year, and in the axil of one of the leaves $L.^1$ is a floral stem (St.) When stolons develop, they generally proceed from the axils of the leaves of the previous year, now present as withered leaf-sheaths, and these stolons consist of two to three stretched internodes, covered by leaf-sheaths; they grow in a horizontal direction, and become terminated by a rosette of leaves, repeating the structure of the mother-shoot. During the first season the stolons remain attached to the mother-shoot, and roots develop freely from the nodes. The number of stolons may vary from one to as many as six, but one or two are the most frequent. The subterranean stem is ascending, densely covered with remnants of leaf-sheaths, and of a soft, fleshy consistence.—The monopodium represents a structure, which is evidently rare; we remember this structure being characteristic of certain species of *Carex*, for instance C. laxiflora, C. digitata, C. Fraseri and some others, which I have described in this journal. A sympodium, however, is the most frequent structure observed in rhizomes especially. Among the Smilaceae Smilax herbacea shows the interesting case of

[3] Rydberg, P. A. Flora of the Rocky Mountains, New York 1917.

the rhizome representing a sympodium, while the aerial stem is a true monopodium. Unfortunately the literature gives little information about these structures, and with regard to the structure of the shoot above ground being a monopodium so distinctly represented by Chionophila, there is no mention of this structure being represented by any of the other Scrophulariaceae; as a matter of fact the word "monopodium" does not occur in any of the American manuals of Botany, dealing with floras of certain regions. Nevertheless it constitutes a character of no small importance, and none of the species of Pentstemon, which I have examined, exhibit this structure. It may be mentioned at the same time, that Arabis dentata exhibits a monopodium exactly as that of Chionophila, and is the only Arabis, known so far, of which the shoot is of monopodial growth. The monopodium occurs also in Claytonia, Calandrinia, Viola etc., which I have described in previously published papers on these genera.

Concerning the inflorescence in Chionophila, this is not a spike, but a unilateral cyme, a monochasium; the floral stem begins with two or three pairs of small, linear, opposite bracts without buds; but above these the bracts become somewhat larger, broader, and we find at each pair a single flower, and a lateral branch, which again terminates in a flower with two bracts and a lateral branch and so on. In Chionophila the composition of the inflorescence is not so very distinct on account of the short internodes, the leaves and flowers being rather crowded, but in Collinsia grandiflora Dougl. the structure is plainly visible, and corresponds exactly with that of Chionophila. In Pentstemon, on the other hand, there is a regular cyme in the axil of each leaf; in P. Newberryi Gr. the axillary cymes are one-flowered, there being only a single flower, but with two bracts, indicating a "dichasium" with two lateral branches suppressed, non-developed.

Characteristic of Chionophila, when compared with Pentstemon, is thus the monopodial ramification of the shoot, and the inflorescence representing a monochasium. The floral structure has been described very exactly by Gray, Bentham and Hooker, except that it seems to have been overlooked, that the calyx, in fresh specimens, is distinctly folded lengthwise as shown in figure 2.

Internal structure of the vegetative organs.

The roots:—In Solereder's treatment of the Scrophu-

lariaceae nothing is said about the root-structure. With respect to C. Jamesii the structure is of special interest, since I observed the development of cork to take place in the peripheral stratum of the cortex, the stratum bordering on the exodermis (fig. 5), and, as we remember, De Bary records only two cases of cork being developed in the peripheral strata of the root-cortex, namely in Clusia and Bignonia capreolata;[4] since then Olivier detected a similar structure in Artanthe pothifolia, Jasminum humile, and Ruyschia Souroubea;[5] to these may be added Tecoma radicans and Cephalanthus occidentalis.[6]

There was no primary root in any of the specimens, which I collected, and the root-system consisted merely of several strong, secondary roots developed from the subterranean part of the stem; these roots were sparingly branched, and only slightly hairy. Inside the epidermis is a thinwalled, contractile exodermis (Ex. in fig. 5), covering an open cortical parenchyma of about twenty layers, with no starch or crystals; a phellogen (Ph.) arises, as stated above, in the peripheral stratum. Inside the cortex follows a thinwalled endodermis (End. in figure 6), surrounding the pericambium (P), in which tangential cell-divisions appear outside the protohadrome, being the only indication of secondary increase in the young roots. The roots are pentarch with five strands of leptome alternating with five short rays of hadrome. The center of the stele represents a relatively broad, thinwalled pith without starch.

As the roots grow older the cortex collapses, and some few secondary vessels develop on the inner flank of the leptome. The main stem, which is terminated by the rosette of leaves, shows the following structure. The upper internodes are cylindric, glabrous and smooth. A thin cuticle covers the slightly papillose epidermis, and the cortical parenchyma is homogeneous, of about twenty strata with distinct intercellular spaces, and containing a little starch. There is no endodermis, and no pericycle, but a band of isolated, small strands of leptome, and a continuous band of cambium, inter- as well as intra-fascicu-

[4] De Bary, A. Vergleichende Anatomie, p. 563. 1877. See also Van Tieghem, Ph. Recherches sur la symétrie de structure des plantes vasculaires. (Ann. sc. nat. Bot. Ser. V, 13. p. 258. 1870.)

[5] Olivier. Recherches sur l'appareil tégumentaire des racines, ibid. Ser VI, 11. p. 124. 1880.

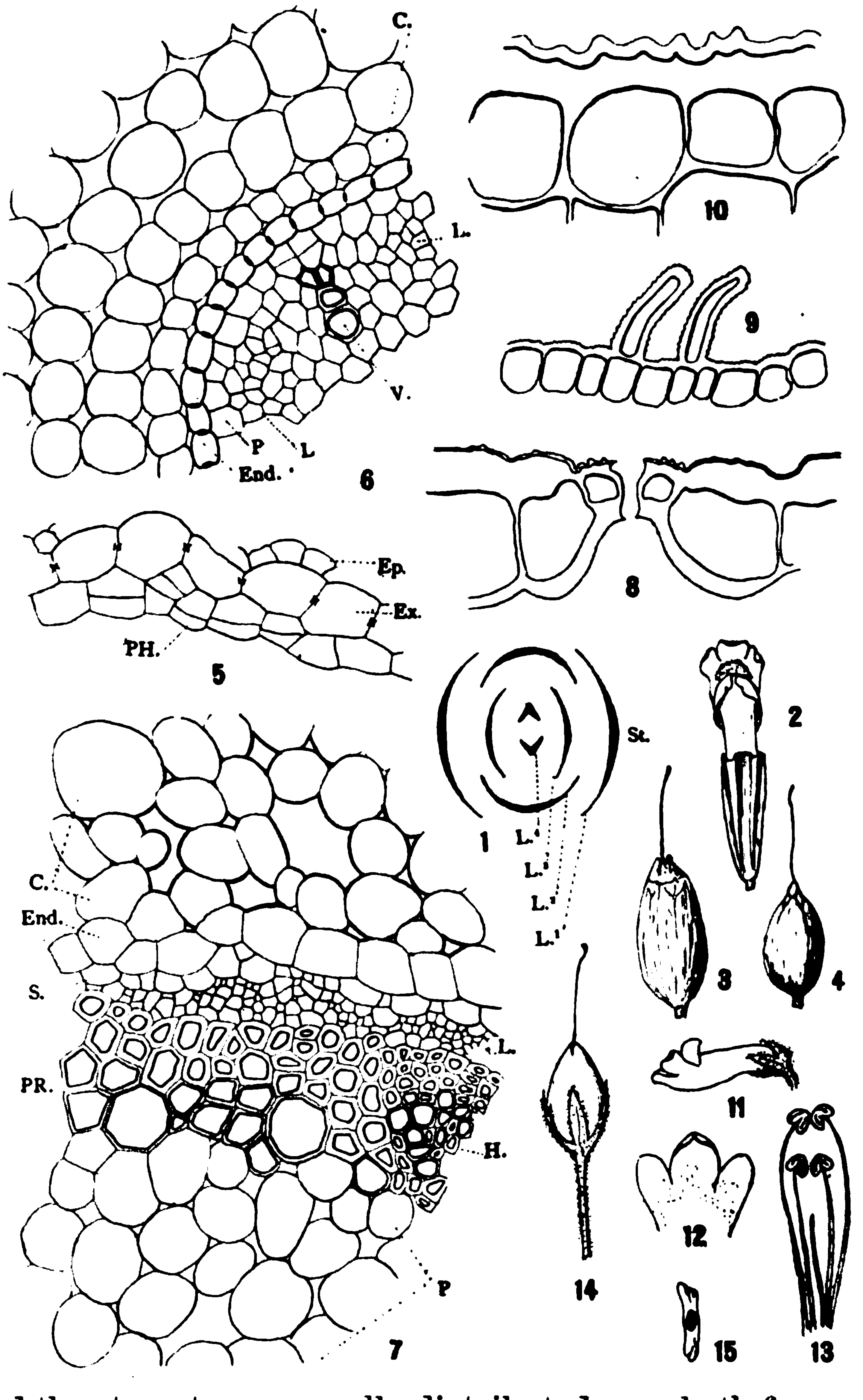
[6] Holm, Theo. Rubiaceae; Bot. Gaz., (vol. 43, p. 155). 1907.

lar; there are eight primary mestome-strands with a few vessels, but with neither mestome-parenchyma nor libriform; the center of the stele contains a thinwalled, starch-bearing pith. Further down, and below the rosette, the epidermis is more or less collapsed, and replaced by two to three layers of cork, developed from the hypodermal structure of the cortex. The cortex is as above; in the stele is no endodermis, but a parenchymatic pericycle, and two concentric bands of leptome, separated by some ten layers of radially arranged parenchyma, a secondary cortex. Some secondary vessels may be seen in the primary mestome-strands, and the hadrome thus constitutes much deeper rays than in the internodes above.

The flower-bearing stem, which is axillary, is two-winged at the base, with the stele circular (in cross section). It is glabrous and smooth, but the cuticle is, here and there, wrinkled longitudinally. The epidermis is thickwalled, especially the outer cell-wall, and the cortex is also somewhat thickened, and consists of six to seven strata, very open from the wide intercellular spaces, and destitute of starch and crystals. Endodermis is barely distinct (End. in fig. 7), and the pericycle is merely present as a single layer of small-celled parenchyma (P. in fig. 7), which is continuous and bordering directly on the numerous small strands of leptome. There are eight primary mestome-strands, containing a few (four) layers of radially arranged, thickwalled, and porous mestome-parenchyma. The interfascicular tissue consists of leptome, and three to four layers of radially arranged, thickwalled parenchyma. The pith is solid, homegeneous, with no starch or crystals (fig. 7). In the wings of the stem is only thinwalled cortex, no collenchyma being developed. This portion of the flower-bearing stem was subterranean, but the structure of the upper, aerial internodes is about the same. However, small hairs with cuticular pearls (fig. 9) occur on the internodes, and the cuticle is more wrinkled. The epidermis is more thickwalled, the cortex contains chlorophyll, and is very open from lacunae of quite considerable width, but otherwise the inner tissues are as described above.

Characteristic of the stem is thus the complete absence of collenchyma and stereome, the only strengthening tissue being represented by the thickwalled, interfascicular parenchyma.

The leaf.—The leaves of the rosette are thick, fleshy, and glabrous; they are held in an almost vertical position,



and the stomata are equally distributed over both faces of the blades. While cuticular striations are very pronounced on the ventral face of the leaf, (fig. 10) the cuticle

is smooth on the dorsal. Viewed "en face" the lateral cell-walls of epidermis are, on both faces, straight, quite thick and porous, especially on the dorsal face; the stomata (fig. 8) are free, and surrounded by mostly four ordinary epidermis-cells. In cross-sections the structure of the cuticle is readily visible (fig. 10), and the outer cell-wall of epidermis appears quite thick. The chlorenchyma consists of four layers of palisade-cells, which cover a very open pneumatic tissue of about eight strata. In the marginal portion of the leaf the palisade-tissue extends to the dorsal part of the blade and there is no mechanical tissue neither stereome nor collenchyma in any part of the leaf. The mestome-strands are collateral, all single, and surrounded by green parenchyma sheaths. The leaf-structure is thus approximately isolateral on account of the distribution of the stomata, but not with reference to the structure of the chlorenchyma. The leaf-structure thus resembles that of the high alpine Claytonia megarrhiza,[7] as far as concerns the distribution of the stomata on both faces of the blade, the several strata of palisade-cells, the thick cuticle and thickwalled epidermis. Bonnier[8] and Wagner[9] have offered some interesting contributions to the knowledge of the structure of alpine plants, and according to these authors the leaf-structure of Chionophila and of Claytonia megarrhiza appears to be the typical one, which characterizes the overwintering leaves of alpine species. And the highly developed assimilating tissue is in correlation with the pronounced intensity of light at the higher elevations, the considerable decrease of carbonic acid in the atmosphere, beside the very short time of vegetation. At the same time these winter-green leaves are protected against too excessive transpiration during the period of the melting of the snow, by means of the very thick cuticle and pronounced thickening of the cell-walls of epidermis. However, only the leaf has been studied by these authors and the Monocotyledones have,

[7] Holm, Theo. Claytonia Gronov, Mem. Natl. Acad. of Sc., vol. 10, Washington.

[8] Bonnier, G. Cultures expérimentales dans les hautes altitudes, (Comptes Rend. Acad. Sc., 1890).

Bonnier, G. Influence des hautes altitudes sur les fonctions des végétaux, (ibid. 1890).

Bonnier, G. Etude expérimentale sur l'influence du climat alpin sur la végétation et les fonctions des plantes, (Bull. Soc. Bot. de France, 1888).

[9] Wagner, A. Zur Kenntniss des Blattbaues der Alpenflauzen und dessen biologischer Bedeutung, (Sitzungsber. Akad. Wiss. Wien, Math. nat. classe, May, 1892).

almost, been passed by in silence. To obtain a more complete idea of the alpine structure and its correlation with the surrounding medium it will be necessary to include the stem as well as the root structure, and to decide whether certain structural peculiarities may be really epharmonic or inherited.

Finally with reference to Pentstemoniopsis this plant shows exactly the same monopodial growth as Chionophila: a terminal rosette of leaves, axillary floral stems, and axillary stolons. The monochasium is also represented in this plant, and more distinctly than in Chionophila, since the inflorescence is more open. The seeds also agree with those of Chionophila (fig. 15), but the flower and the fruit resemble those of Pentstemon. The habit of the plant thus corresponds with that of Chionophila, the deeply cleft calyx and the free capsule with those of Pentstemon. The corolla with the lower lip bearing short-papillae instead of distinct hairs as in Chionophila is of small importance, but the gibbous base, and the horizontal position of the flower render the plant distinct from both, and especially when combined with the monochasial ramification of the inflorescence.

Pentstemoniopsis is undoubtedly a good genus, if we include the vegetative characters, and the structure of the inflorescence in the diagnosis.

EXPLANATION OF FIGURES.

FIG. 1. Chionophila Jamesii. Diagram of the shoot; for explanation see the text.

FIG. 2. The flower, seen from above; enlarged.

FIG. 3. The fruit surrounded by the marcescent calyx and corolla; enlarged.

FIG. 4. The capsule removed from the calyx and corolla; enlarged.

FIG. 5. Cross-section of a secondary root; Ep.=epidermis; Ex.=exodermis; Ph.=phellogen; X 320.

FIG. 6. Cross-section of inner part of same root; C.=cortex; End.=endodermis; P.=pericycle; L.=leptome; V.=vessels; X 496.

FIG. 7. Cross-section of inner part of stem; S.=pericycle; P.=pith; H.=hadrome; other letters as above; X 320.

FIG. 8. Ventral epidermis of leaf with a stoma; X 496.

FIG. 9. Epidermis of stem with hairs; X 320.

FIG. 10. Dorsal epidermis of leaf; X 496.

FIG. 11. Pentstemoniopsis Tweedyi (Rose) Rydbg. The flower, side-view; enlarged.

FIG. 12. Lower lip of flower; enlarged.

FIG. 13. The stamens, four fertile, one sterile; enlarged.

FIG. 14. The fruit; enlarged.

FIG. 15. The seed; enlarged.

Clinton, Md., April, 1920.

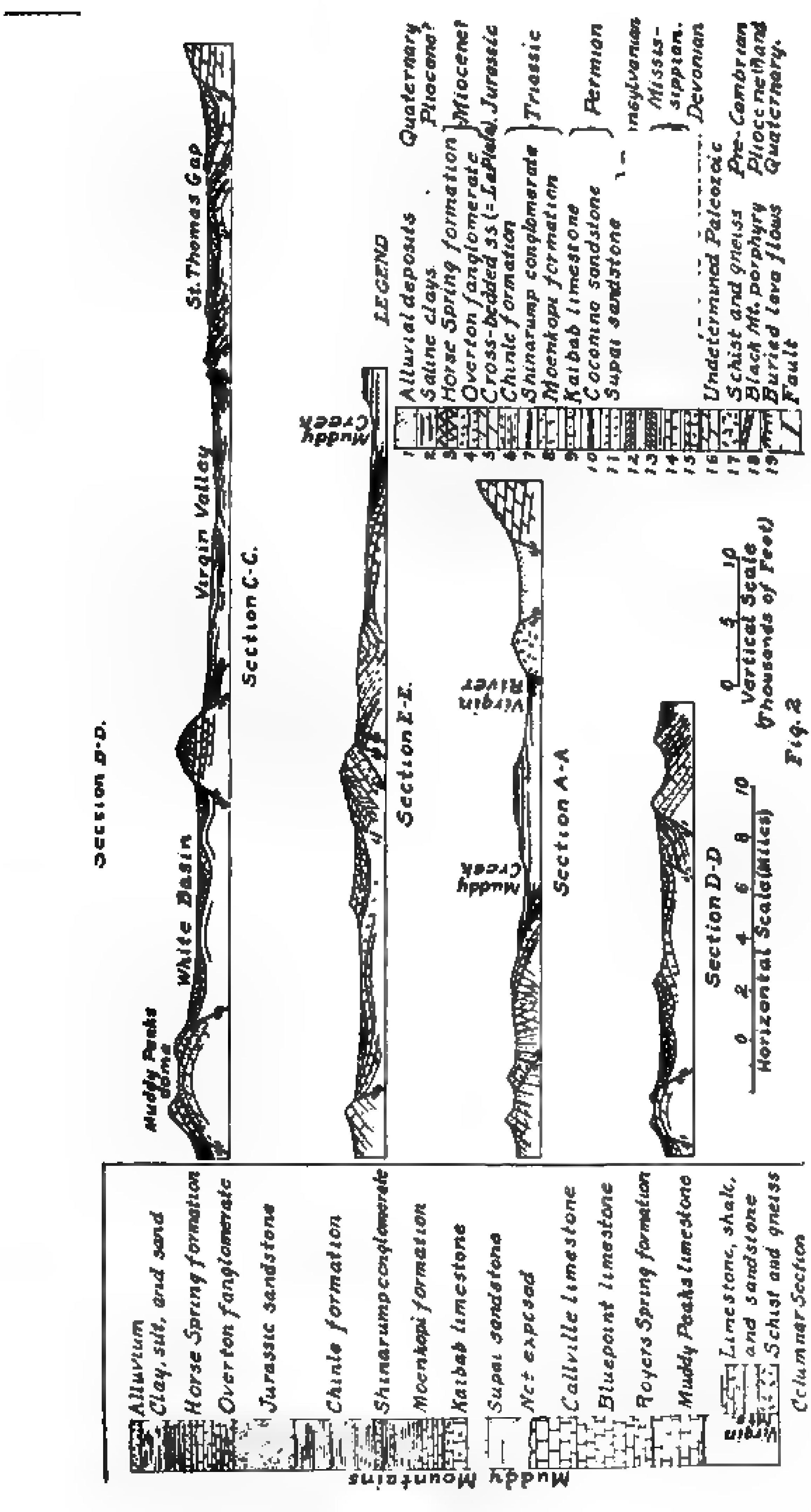
ART. IV.—*Geology of the Muddy Mountains, Nevada, with a Section to the Grand Wash Cliffs in Western Arizona*[1]; by CHESTER R. LONGWELL.

INTRODUCTION.

The area with which this paper is concerned is in southeastern Nevada and northwestern Arizona, as indicated on the accompanying index map (fig. 1). The general region of which this area is a part has more than one strong appeal to the geologist. It is practically unmapped, and hence has the lure of the unknown. The pioneer scientists who traversed the Plateau and Great Basin regions gave only passing notice to the Virgin and Muddy mountains, and the inaccessibility of the region has discouraged later efforts. As a result, a large area still presents opportunities for scientific work of an exploratory nature. Moreover, the location of the region near the edge of the Basin Range country and immediately adjacent to the Plateau Province gives it a critical interest, because the stratigraphic, structural, and physiographic relations of Basin to Plateau must be determined largely by a study of this border zone. Are the rocks west of the Grand Wash Cliffs fundamentally different from those to the east? What is the nature and what the age of structure lines dividing the two provinces? To what extent does the physiography of the region help in unravelling the more recent geological history? These questions concern matters which are not only of interest in themselves, but are fundamental in the larger problems touching the origin and development of the Plateau, the eastern part of the Great Basin, and the Colorado River system.

Previous reports.—The Whipple, Ives, and Wheeler parties did not map the area considered in this report, but made reconnaissance surveys of closely adjacent areas. Dutton included in his atlas of the Grand Canyon district a generalized geologic map of the Grand Wash and the eastern part of the Virgin Mountains. The first representation of the geology of the Muddy Mountains and the lower Virgin Valley appeared in 1903, on Spurr's map of southern Nevada, included in Bulletin 208 of the U. S.

[1] Published by permission of the Director of the United States Geological Survey.


Muddy Mountains
Alluvium
Clay, silt, and sand
Horse Spring formation
Overton fanglomerate
Jurassic sandstone
Chinle formation
Shinarump conglomerate
Moenkopi formation
Kaibab limestone
Supai sandstone
Not exposed
Callville limestone
Bluepoint limestone
Royers Spring formation
Muddy Peaks limestone
Virgin
Limestone, shale, and sandstone
Schist and gneiss
Columnar Section
Muddy Peaks dome
White Basin
Virgin Valley
St. Thomas Gap
Section C-C.
Section E-E.
Muddy Creek
Virgin River
Section A-A
Section D-D
Horizontal Scale (Miles)
Vertical Scale (Thousands of Feet)
Fig. 2
LEGEND
Alluvial deposits
Saline clays
Horse Spring formation
Overton fanglomerate
Cross-bedded ss (=LaPlata)
Chinle formation
Shinarump conglomerate
Moenkopi formation
Kaibab limestone
Coconino sandstone
Supai sandstone
Undetermined Paleozoic
Schist and gneiss
Black Mt. porphyry
Buried lava flows
Fault
Quaternary
Pliocene?
Miocene?
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Pre-Cambrian
Pliocene and Quaternary

Geological Survey. The portion of the map representing the Muddy and Virgin mountains was based on scant information, and the author made no claim of its accuracy.

Nature of this paper.—The report of which this paper is an abstract will appear as a publication of the U. S. Geological Survey, and will present in detail the results obtained in five months of field work in 1919. This abstract will state only the most essential facts and conclusions regarding the topography, stratigraphy, structure, and physiography of the region mapped.

Acknowledgments.—The writer wishes to express his thanks to members of the Geological Department of Yale University, who secured research funds for prosecuting the field work on which this paper is based. Acknowledgment is also due the U. S. Geological Survey, which furnished surveying instruments and field equipment, although the writer was not a regular employee of that organization. Mr. Harold S. Cave, at that time a graduate student in the University of Missouri, spent several weeks in the field and gave valuable assistance. During the preparation of the report continued interest and advice from Professors Charles Schuchert and H. E. Gregory were of especial assistance. The most sincere thanks are due them and other members of the faculty who gave helpful suggestions.

Geography.

Climate and drainage.—Southeastern Nevada has an average annual rainfall of less than 6 inches, and is part of a large arid region. Due to the proximity of Colorado River, however, the drainage is entirely exterior. Virgin River is a permanent stream, receiving its supply in part from the mountains of southern Utah, and in part from its principal tributary, Muddy Creek, which has its source in a number of large springs. Other stream channels reach every part of the area, but all are dry except at times of infrequent rains.

Topography.—The general uniformity of surface which characterizes the Colorado Plateaus ends abruptly at the Grand Wash Cliffs. To the west, rugged, barren ranges, trending generally north and south, are separated by wide structural valleys of low elevation. The Virgin Mountains have a number of sharp peaks, the highest reaching an elevation of 7,700 feet. St. Thomas Gap, a low pass of

structural origin, permits easy passage between the Grand Wash and Virgin valleys. The highest part of the Muddy Range is Callville Mountain, an abrupt mass shaped roughly like a large letter "C" with the opening toward the south. The general elevation of the mountain above sea-level is about 3,000 feet, but many peaks rise to an elevation of 4,000 feet or higher. Muddy Peaks, the highest points, are nearly 5,800 feet above sea-level. Both north and south of Callville Mountain the average elevation is slightly more than 2,000 feet, and abrupt ridges rise several hundred feet higher. Everywhere the surface is nearly destitute of vegetation and has been carved into extremely rugged forms.

The valleys of Grand Wash, Virgin River, and California Wash are each several miles in width, and have a total area approximately equal to that of the intervening ranges. The stream courses occupy comparatively narrow inner valleys, from which there is a gradual rise toward the mountain walls on a series of broad terraces, partly dissected into badlands. Colorado River has cut canyons through the ranges, but its valley is wide and comparatively open in crossing the intermontane troughs. South of the Muddy Range the Colorado is less than 700 feet above sea-level.

Rock Series and Formations.

West of the Grand Wash Cliffs sedimentary formations are separated into two especially distinct groups. The first is a thick series resting on pre-Cambrian schists and ending upward with Mesozoic sediments. This group clearly corresponds to the series exposed in the Grand Canyon and on adjacent plateaus, and, as in the case of that series, the limestones, sandstones, and shales belonging to many periods have remarkable conformity among themselves. The second group has a distinctly younger aspect, and is separated from the older series by an unconformity of the first order. Below this break the youngest rocks exposed are not higher in the time scale than middle Mesozoic, whereas the oldest rocks of the younger series are probably later than middle Tertiary. Other unconformities within the younger group indicate continued unrest and an incomplete sedimentary record since the disturbances which first tilted the older rocks.

Era	Period	Epoch	Formation	Thickness (in feet)
Cenozoic	Quaternary		Various alluvial deposits	0- 400
			Unconformity	
	Tertiary	Pliocene?	Saline clays, silt, and sand	200-1800
			Unconformity	
		Miocene?	Horse Spring formation	1000-2800
			Overton fanglomerate	20-3500
			Great Unconformity	
Mesozoic	Jurassic		Cross-bedded sandstone (Equivalent to) (the LaPlata)	750-2000
	Triassic		Chinle formation	800-3200
			Shinarump conglomerate	10- 200
			Disconformity	
			Moenkopi formation	1200-1600
			Disconformity	
Paleozoic	Permian		Kaibab limestone	400- 700
			Coconino sandstone	0 - 75
			Supai sandstone	1000+
	Pennsylvanian		Not exposed. Unknown thickness	
			Callville limestone	1100+
			(No unconformity observed)	
	Mississippian		Bluepoint limestone	900±
			Rogers Spring formation	600±
			Disconformity	
	Devonian (and older?)		Muddy Peaks limestone	1200+
	Cambrian (and later)		Sandstone, quartzite, shale, and limestone. In Virgin Mountains.	

Rocks of the Virgin Mountains.

Exposures of pre-Cambrian rocks occupy large areas both north and south of St. Thomas Gap. The rocks are schists and gneisses, injected with coarse-grained granite. Above these crystalline rocks lie 70 to 100 feet of red arkose, 150 feet of gray quartzite and sandstone, several hundred feet of greenish shale, and limestones thousands of feet thick. The limestones are in large part Pennsylvanian, Mississippian, and Devonian, but probably the Ordovician and Cambrian periods are also represented. The clastic sediments at the base probably

correspond to the Middle Cambrian Tapeats sandstone and Bright Angel shale of the Grand Canyon district.

Rock formations younger than the Paleozoic are exposed in St. Thomas Gap. They are identical with formations in the Muddy Mountains.

Rocks of the Muddy Mountains.

Paleozoic Formations.

Devonian System.—Limestones of Devonian age are the oldest rocks recognized in the Muddy Mountains. They are in Callville Mountain, a great block which has been thrust over Jurassic sandstone. All of the beds between the overthrust plane and recognized Carboniferous are here referred to the Devonian, but further work may show that some of the lower strata belong to older periods. Devonian fossils were found in a zone about 50 feet thick, more than 300 feet below the base of the Mississippian. Below this fossiliferous horizon there are 900 feet of limestone in which no fossils were found except a few algæ. As the beds are of the same general nature and as no unconformity could be found in the series, the entire thickness of 1,200 feet is tentatively included in one formation, which will here be called the *Muddy Peaks limestone* because of its prominence in the Muddy Peaks mass.

The limestone is dense and hard, and many beds have a siliceous appearance. Layers are regular and heavy, ranging from 2 to 20 feet in thickness. In color they are either very dark from included carbonaceous matter, or decidedly light, beds or zones of the two alternating. Lenses and thin layers of sandstone occur at intervals, especially near the top of the formation. At the base brecciation and shattering are extreme through a thickness of 100 to 500 feet.

Most of the fossils collected from the formation have been misplaced, and therefore a complete list is not available for publication in this paper. The following partial list has been identified by Dr. E. O. Ulrich: *Heliophyllum* sp. undet. (calyx less than 1/2 inch in diameter), *Zaphrentis* sp. undet. (calyx 1 inch or less in diameter), small Stromatoporoid of undetermined genus and species, *Atrypa* aff. *reticularis* (differs from the typical form in

having finer plications), and *Platyschisma? ambiguum* Walcott.

If the writer's field determinations are correct, the fauna also contains *Spirifer whitneyi.* Dr. Ulrich states that this fauna evidently represents that of the Devonian Nevada limestone found at Eureka, Nevada. The horizon is Upper Devonian.

Mississippian System.—A plain disconformity separates the Muddy Peaks limestone and higher sediments. Above this break at least 1,500 feet of carbonaceous limestone, containing an abundance of chert at many horizons, yields fossils of Mississippian age. No physical break was seen in this series of beds, but the faunas of the upper and lower portions are so strikingly different that the limestone may be separated into two formations. The following forms were found in the lower 600 feet: *Triplophyllum* sp., *Leptopora* aff. *typa, Leptæna analoga, Schuchertella* aff. *chemungensis, Chonetes loganensis, Productus* sp., *Camarotæchia metallica, Spirifer centronatus, Spiriferina solidirostris,* and *Reticularia cooperensis?*

Dr. G. H. Girty, who identified the forms, refers this fauna definitely to the Lower Mississippian, correlating the horizon with the Madison limestone. This formation is prominently exposed near Rogers Spring, and will be called the *Rogers Spring formation* in this paper. In addition to its faunal peculiarities it is characterized by the presence of a considerable thickness of dark quartzite in the upper half.

The younger Mississippian formation yielded the following forms: *Triplophyllum* sp., *Cyathaxonia* sp., *Fenestella* sp., *Derbya* aff. *kaskaskiensis, Chonetes* aff. *loganensis, Composita* aff. *subquadrata, Productus* aff. *scitulus, Pustula* aff. *indianensis, P.* aff. *arkansana, Spirifer* sp., *Conocardium* n. sp., *Leptodesma* aff. *spergenensis, Pleurotomaria* n. sp., *Paraparchites* sp., and *Bairdia* sp. Dr. Girty pronounces this fauna Upper Mississippian, corresponding to the fauna of the Brazer limestone of northern Utah. The formation will be referred to as the *Bluepoint limestone,* because it forms the corner of Callville Mountain which is locally called Bluepoint.

Pennsylvanian System.—In Callville Mountain the Bluepoint limestone is overlain by at least 1,100 feet of dark gray, heavy bedded limestone containing the follow-

ing fossils: *Triplophyllum* sp., *Productus cora, Pustula nebraskensis, P. nebraskensis* var., *Dielasma bovidens, Spirifer cameratus, S. rockymontanus, S.* sp., *Composita subtilita, Edmondia* sp. On the basis of this fauna Dr. Girty correlates the limestone with the Magdalena group of New Mexico. In this paper the formation will be called the *Callville limestone,* because of its prominence in Callville Mountain. An indeterminate thickness has been eroded from the sections studied in the Muddy Mountains, and the contact with the overlying Supai sandstone was not seen at any place. Limestone with similar fossils and lithology was recognized in the Virgin range. In the Grand Wash Cliffs, limestone containing Pennsylvanian fossils lies immediately beneath the typical Supai sandstone, but the limestone does not resemble the Callville formation lithologically. The thick series of strata in the lower cliff contains an abundance of dolomite, and does not resemble any part of the Callville Mountain Carboniferous section.

The lower part of the Supai sandstone may be of Pennsylvanian age but for convenience the entire formation will be discussed under the Permian.

Permian System.—The *Supai sandstone* is prominently exposed in the upper Grand Wash Cliff, and in tilted fault blocks to the west. In the upper cliff the sandstone is more than 1,000 feet thick, and practically all of it is bright red, fine-grained, and regularly bedded. In the Virgin and Muddy mountains cross-bedding is very prominent in the formation, gypsum and gypsiferous shale occur at several horizons, and in the most westerly exposures the typical red color is largely replaced by grey. No fossils were found in the sandstone, but at least a part of it is assumed to be Permian, corresponding to the Upper Supai described by Schuchert in the Grand Canyon district. In the lower Grand Wash Cliff, Pennsylvanian fossils were found near the top of beds which apparently correspond to Noble's basal Supai in the Grand Canyon. These beds may mark the upper limit of the Pennsylvanian, or the Pennsylvanian-Permian contact may lie at a higher horizon, within the typical red sandstone.

Typical *Coconino sandstone* lies above the Supai in the Upper Cliff, in Grand Wash Valley, and in the Virgin Mountains. In these exposures the maximum thickness

observed was 75 feet, and the formation thins consistently westward, losing its identity in the Muddy Range.

The *Kaibab limestone* has two thick limestone members, both composed of dark gray, cherty limestone in heavy beds. In Grand Wash these members are separated by red sandstone, but in the Virgin and Muddy Mountains the dividing horizon is occupied by massive gypsum which is locally 100 feet thick. At the base the formation has alternating layers of sandstone and limestone, forming a variable thickness. The total thickness of the formation ranges from 400 to 700 feet. Fossils are

FIG. 3.—Upper Grand Wash Cliff, 10 miles north from the mouth of the Grand Canyon. Thickness of strata exposed about 900 feet. 1, upper part of Supai sandstone; 2, Coconino sandstone; 3, alternating sandstone and limestone layers at base of Kaibab limestone; 4, lower heavy limestone member of the Kaibab; 5, upper heavy limestone member. Bench between 4 and 5 due to weak shale and sandstone.

abundant in the heavy limestone members. Dr. Girty has identified the following list: *Fistulipora* sp., *Leptopora* n. sp., *Phyllopora* n. sp., *Cystodictya* sp., *Enteletes?* n. sp., *Derbya* sp., *Productus ivesi, P. occidentalis, P. semireticulatus, Marginifera lasallensis?, Pustula subhorrida, P. montpelierensis, Squamularia* aff. *guadalupensis, Composita subtilita, C. mexicana, Griffithides* sp., and *Acanthopecten coloradoensis.*

Dr. Girty states that this fauna is Permian, corresponding to that of the typical Kaibab and also to the

fauna of the San Andreas limestone in the Manzano Group of New Mexico.

Mesozoic Formations.

Interval between eras.—A distinct disconformity separates the Kaibab limestone from Mesozoic sediments. Local depressions or valleys 50 to 100 feet deep, cut into the Kaibab in early Triassic or pre-Triassic time, are filled with chert and limestone fragments from the underlying rock. No angular divergence was found between Paleozoic and Mesozoic formations.

FIG. 4.—"Magnesite" of the Horse Spring formation, in Muddy Valley. Beds dip 32° N.E. Thickness of 300 feet shown in figure.

Triassic System.—The lower Triassic is represented by thin-bedded limestone, shale, and sandstone forming a total thickness ranging from 1,200 to 1,600 feet. In the Muddy Mountains limestone makes up practically half of the thickness. Typically the layers are regular, but are very thin, beds more than a foot thick being exceptional. Shale, sandstone, and gypsum members occur at intervals, and abundant ripple-marks indicate shallow water during deposition. Marine fossils, dominantly pelecypods, are found at many horizons. The upper part of the deposits are continental, and consist mainly of shale. with abundant gypsum. Tracks of small reptiles occur in the shales.

The following forms, found in the limestones, were identified by Dr. Girty: *Aviculipecten utahensis, A.* spp. 1 and 2, *A.* n. sp., *Pseudomonotis* n. sp., *Myalina* n. sp., *Pteria?* sp., *Sedgwickia?* n. sp., *Myophoria* n. sp., *M.* aff. *lineata, Pleurotomaria?* n. sp., *Pleurophorus?* n. sp., *Pseudomelania?* n. sp., *Murchisonia?* sp., and casts of starfishes.

Although this list is not diagnostic in itself, it serves to correlate the horizon with beds in Arizona, Utah, and Idaho in which, Dr. Girty states, ammonites have been found, proving a Lower Triassic age for the horizon. Very clearly the formation corresponds closely to the

FIG. 5.—Unconformable contact of Pliocene(?) intermontane deposits and Horse Spring beds. Valley of Muddy Creek.

Kanab Valley "Permian," to the "Lower Shinarump" of northern Arizona, and to the Moenkopi formation of Arizona, New Mexico, and Utah. The name *Moenkopi* has been applied to the beds of this horizon over a large region, and this name will also be used here for the formation in the Muddy Mountains, inasmuch as there is no reasonable doubt regarding the correlation.

A disconformity separates the top of the Moenkopi formation from the *Shinarump conglomerate,* which ranges in thickness from 10 feet to 200 feet and varies in composition from coarse conglomerate to conglomeratic sandstone. Pebbles are mainly quartzite and chert, and are

well rounded. Beds are local and lenticular, and the entire formation is characterized by extreme crossbedding. Fragments of silicified wood are abundant, and large logs are common, especially near the top. Descriptions of the conglomerate in the Navajo country, 300 miles to the east, are equally accurate for the formation in the Muddy Mountains. With the exception of the petrified wood no fossils were found, and the conglomerate is called Upper Triassic merely to agree with its present classification in the Colorado Plateaus.

The Shinarump conglomerate is overlain, without apparent unconformity, by the *Chinle formation,* a thick series of sandstones and gypsiferous shales. Near Colorado River this formation is 800 feet thick, and at least a third of the thickness is made up of coarse sandstone layers, many of them conglomeratic. Northward the thickness increases to 3,000 feet within 20 miles, and the coarse materials almost disappear. Near Muddy Creek the greater portion of the formation consists of red gritty shale and fine-grained sandstone, with an abundance of gypsum, both primary and secondary. Ripple-marks are common, and silicified wood occurs at some horizons. Evidently the deposits are continental, and the source was in highlands which lay to the south, probably in central or southern Arizona. The formation corresponds closely in lithologic character and in stratigraphic relations to the Chinle formation of the Navajo country and to the Dolores of southwestern Colorado; and in this report the name *Chinle* is extended to the horizon in the Muddy Mountains, although no faunal evidence of its age was found in that region.

Jurassic System.—No unconformity was found between the Chinle formation and the overlying Jurassic sandstone, which is heavy bedded, cross-bedded on a large scale, and typically bright red, although gray is the predominant color locally. As a rule the false beds are straight and meet the true bedding planes at high angles; but tangential cross-bedding also occurs, and in some sections it is very conspicuous. The sand grains are fine to medium in size and show indications of wear by the wind. Probably both wind and water had a part in the final deposition of the sand. Without doubt the formation was laid down in an arid climate, and its great thickness —ranging from 800 to at least 2,000 feet—required neigh-

boring highlands of considerable elevation to furnish the materials. The sandstone corresponds to the La Plata Group of Arizona, New Mexico, and Utah; and it is probable that these widespread deposits of remarkably similar character had a common source in a mountain range to the south, perhaps the same highlands which furnished materials for the Chinle formation. The sandstone is here referred to the Jurassic period to agree with the present classification of the La Plata Group.

Cenozoic Formations.

Tertiary deposits.—The general structural conformity of sedimentary beds in the Muddy Mountains ends with the Jurassic sandstone. Younger sediments record a new order. A widespread surface of erosion was cut across the upturned edges of Mesozoic and Paleozoic strata, and on this surface the first record is found in a coarse, heavy alluvial fan deposit which embodies fragments of all the older local rocks. In its most typical phase the deposit consists mainly of limestone fragments, angular or slightly worn, with sand filling the interstices, and with a firm cement of calcium carbonate. Beds are lenticular, and fragments of many sizes are jumbled together with evidence of only the rudest attempt at sorting. Limestone masses 3 to 25 feet in diameter are not uncommon. Exposures of the deposit are distributed over the entire area, but the thickness varies greatly. Near Bitter Spring it is 20 feet thick, whereas near Overton the thickness is more than 3,000 feet. Adjacent to the Virgin Mountains the formation has a nearly uniform thickness, averaging 25 feet. Because of the peculiar character and evident origin of the deposit, Lawson's term *fanglomerate* is especially appropriate as a lithologic designation, and in this paper the formation will be called the *Overton fanglomerate,* from its typical development near the settlement Overton in the Muddy Valley.

The Overton deposits indicate rugged topography and arid or semi-arid climate. Near the end of the fan stage relief became more subdued, for the coarse sediments grade upward into fine playa and lake deposits which have a total thickness of at least 2,500 feet. These beds consist of sandstone, limestone, magnesium carbonate, shale, tuff, and gypsum, and the change from one type of sedi-

ment to another is often abrupt horizontally as well as vertically. Limestone and magnesian beds make up about a third of the thickness, and form the most conspicuous part of the formation. Much of the limestone is practically pure calcium carbonate, lies in heavy, regular beds, and has a delicate pink color on fresh surfaces. Oolitic or concretionary structure is common. No fossils were found, and it is probable that the limestone formed as a chemical precipitate in basins of brackish water. In many parts of the area the limestone horizon is occupied by 100 to 300 feet of a snow white deposit which is almost pure magnesium carbonate; and in other sections the two types of deposit interfinger. Thin beds of volcanic ash occur at short intervals in the limestone and "magnesite" and are also found at higher horizons.

For this series of beds the name *Horse Spring formation* is proposed, because of the prominent exposures near Horse Spring, in the Virgin Mountains. No fossils were found in these deposits or in the Overton fanglomerate, and their exact age is therefore undetermined. In lithology, in degree of deformation, and in general regional relationships the Horse Spring deposits compare well with the Siebert and Esmeralda formations of southwestern Nevada. Both of the latter formations are of Upper Miocene age, and the Overton and Horse Spring sediments will be referred tentatively to the same epoch.

All of the large intermontane valleys contain thick deposits of silt, clay, and sand which have suffered much less deformation than the next older formations. Wherever contacts were observed the intermontane sediments, lying horizontally or only moderately folded, rest on the bevelled edges of steeply tilted Horse Spring and Overton beds. For the most part the silt is in massive layers 6 inches to 2 feet thick, separated by lenticular layers of sand imperfectly cemented. Clay free from grit occurs in very minor quantity. Adjacent to the mountains the base of the sediments consists of coarse, unassorted gravel; but at a higher horizon the finer materials are in direct contact with solid rock ridges and have thin lamination, indicating that at least a part of the deposition occurred in lakes deeper and more permanent than playa lakes. In the Virgin Valley, beds of rock salt 50 to more than 100 feet thick occur in the lower 400 feet of the sediments, and gypsum layers are common through a much

greater thickness. Apparently the maximum exposed thickness of the sediments is nearly 2,000 feet, and an undetermined amount has been removed by erosion. The formation has the essential characteristics of interior basin deposits in an arid or semi-arid climate. No diagnostic fossils were found in these beds, and reference of the formation to the Pliocene is made tentatively, because of apparent correspondence to deposits of that age near Panaca, 100 miles to the north.

Quaternary deposits.—Various alluvial deposits are distinctly younger than the sediments of probable Pliocene age, and will be grouped as Quaternary, with the following classification according to their nature and origin: (1) Coarse gravels and sand, with a thickness ranging from 10 to 300 feet, underlying high surfaces of aggradation. These deposits are practically uncemented except in the upper 4 or 5 feet, where a rich matrix of calcium carbonate or gypsum forms a resistant caliche. (2) Remnants of consolidated fan, talus, and travertine deposits adjacent to mountain walls. (3) Alluvial fans still or until quite recently in process of building. (4) Recent talus cones and slope covers. (5) Valley filling of banded silt and sand of undetermined thickness. (6) Sand dunes, in river valleys and on terrace surfaces.

Igneous rocks.—The north end of the Black Mountains is composed mainly of intrusive porphyries and buried flows, all probably of Pliocene age or later. A thin flow of augite-olivine basalt, apparently derived from the Black Mountain volcanic center, is included in the saline clays of Virgin Valley and extends northward almost to St. Thomas. In Grand Wash Valley two flows of olivine basalt, separated by a vertical interval of 70 feet, are buried in Quaternary gravels. Apparently their source was to the north.

Structure.

The region has been affected by both faulting and folding, and the structure is complicated. Four principal groups of structural features are recognized, as follows: (1) Great faults or fault zones which separate adjacent ranges. (2) Intersecting faults which divide each range into a mosaic of blocks. (3) Folding, both moderate and intense. (4) Overthrusting, apparently of a major character. The intermontane faults will be discussed first,

and other structural features will be considered in their relation to separate ranges.

Intermontane faults.—At the top of the upper Grand Wash Cliff the Kaibab limestone lies approximately 4,000 feet higher than tilted blocks of the same formation on the floor of Grand Wash Valley. The valley represents a zone of large normal faults, all with downthrow on the west. The largest of these displacements, represented in part by the Cliffs, amounts to about 7,000 feet near Colorado River but decreases to the north. Since the original faulting, the upper cliff has receded 2 to 6 miles, and the lower cliff has been greatly dissected. The greater retreat of the upper cliff is due mainly to the weak Supai sandstone at its base; but it is possible that the faulting occurred in stages separated by long time intervals, and therefore that the upper cliff has suffered much longer erosion than the lower. Lack of coarse materials in the intermontane clays near the foot of the lower cliff suggests recurrence of faulting in comparatively recent time.

Virgin Valley is also an important fault zone. Closely spaced faults parallel to the river and with large downthrow to the west are represented by high scarps on the west side of the Virgin Range. North of St. Thomas outcrops of pre-Cambrian schist end abruptly on the east side of the river, and on the Muddy Mountain side Mesozoic and Tertiary sediments dip steeply eastward. The total displacement amounts to many thousands of feet, but precise measurement is not practicable.

Faults bound the Muddy Mountains on the west, at least in part, and it is probable that California Wash is a fault zone similar to Virgin Valley.

Structure of the Muddy Mountains.

In the Muddy Mountains there are three well defined structural divisions, separated by lines extending generally east and west. The northern division, between the Arrowhead fault and Muddy Creek, is characterized chiefly by folding, with faulting an important but secondary factor. The central division consists of Callville Mountain, an irregular remnant of an overthrust block which is bounded as well as cut by large normal faults. In the southern division there is a series of folds with axes extending approximately northeast and southwest,

cut and modified by a number of normal faults. This folding continues into the Black Mountains, and hence there is no definite structural division between the two mountain groups.

Northern division.—North of Callville Mountain the outcrops of Mesozoic formations have the shape of a large letter "L", due to the intersection of two anticlines at nearly right angles. In the Narrows anticline the beds have been tightly compressed and overturned to the east, and a large strike fault has caused a duplication of formations at the surface. East-west faults have further complicated the structure, and near the Arrowhead road the Kaibab and Moenkopi limestones have been thrust over Jurassic sandstone, probably in connection with the Callville Mountain overthrust. The Arrowhead anticline is a broad asymmetric fold which plunges beneath the intermontane clays at the east end, and at the west dies out as it meets the stronger fold from the north. The Overton and Horse Spring beds are involved in the Arrowhead fold, and near the Narrows of Muddy Creek they are moderately folded parallel to the Narrows anticline. Numerous minor faults affect all formations.

Central Division.—On the north side of Callville Mountain, Devonian and Carboniferous limestones lie at an elevation many hundreds of feet higher than adjacent Mesozoic sediments, and the fault plane between formations shows large downthrow on the south, indicating that the older rocks were once in an even higher position with respect to the younger. This relation suggests overthrusting, and north of Muddy Peaks the actual thrust plane is well exposed. Devonian limestone lies on the Jurassic sandstone, and the contact is marked by a smoothly polished surface, above which the limestone is intensely shattered through a thickness ranging from 100 to 500 feet. This shattering is also conspicuous along the north base of Callville Mountain. The vertical displacement due to the overthrust is at least 9,000 feet, and yet the thrust plane is practically parallel to the bedding. This fact suggests that the movement affected a large area. Crumpling and minor thrusting indicate that the direction of overthrusting was from southwest to northeast. Evidently that portion of the block which formerly lay north

of Callville Mountain has been removed by erosion, whereas to the west and south the strata involved in the movement have been carried downward by normal faulting, leaving Callville Mountain as the only remnant now exposed.

Subsequent to the overthrusting, pronounced doming has occurred north of Muddy Peaks, permitting the stripping which has exposed the thrust plane. Normal faulting, accompanied by tilting of blocks, has also affected Callville Mountain, and many of the scarps have a remarkably fresh appearance. The Arrowhead fault is marked by a fault-line scarp, the thrown block now occupying the higher position. Exposed portions of the actual plane have striations which dip westward 40° from the horizontal, thus indicating that the shove was greater than the throw. The Rogers Spring and White Basin faults, each with displacement of at least 2,500 feet, bound a high, narrow horst. The dropping of fault blocks is chiefly responsible for the depression known as White Basin. Faults with large displacement affect the western part of Callville Mountain, and a number of these bound narrow tongues of Horse Spring limestone which have been dropped into the mountain mass.

Southern division.—The axes of Bitter Wash and Sandstone Spring anticlines are parallel, and both are essentially parallel to the long axis of Muddy Peaks dome. Moreover, the three structures are almost equally spaced, and the intensity of folding is practically the same in all. The Sandstone Spring anticline plunges sharply at both ends, and therefore it is actually a dome with elliptical plan. Without doubt the three folds belong to the same series, and thus the central and southern divisions of the Muddy Mountains and the northern part of the Black Mountains are to some degree a unit in structure. Both the Bitter Wash and Sandstone Spring anticlines are greatly modified by faulting.

Deformation of intermontane deposits.—On the south side of Muddy Valley the intermontane clays show little disturbance, but have a perceptible general inclination toward the valley ranging from 100 to 200 feet per mile. In the Virgin Valley, however, the clays have been considerably folded. Northeast of Bluepoint a zone of disturbed strata follows the direction of the Rogers Spring

fault, the net result being a monoclinal dip southeast by east, although strong dips to the northeast occur locally. Near the line of greatest disturbance dips of 20° are common and inclinations as high as 40° were observed. This folding probably occurred in connection with recurrent movement on the Rogers Spring fault within comparatively recent time.

An anticline following the course of Virgin River for several miles south of Muddy Creek is indicated by persistent dips ranging from 20° to 35°, westward on the west side of the stream and eastward on the east side. Four miles south of St. Thomas a broad, gentle swell intersects the steeper north–south fold, producing a dome. A more pronounced east and west anticline affects the clays on both sides of the river immediately north of Bitter Wash, where the underlying Horse Spring beds have been exposed by erosion. Between Callville Mountain and Virgin River the clays have a basin-like structure, produced by combination of the anticlines mentioned and the monoclinal dip eastward from the Rogers Spring fault.

Structure of the Virgin Mountains.

Only a small part of the Virgin Mountains was studied in connection with this report, and therefore the major framework cannot be fully described. Northeast of St. Thomas the end of the principal range is a large anticline with a metamorphic core, the thick sediments dipping northwest and southeast from the axis, which extends generally northeast. South of St. Thomas Gap the rocks dip steeply eastward in a great tilted block in which both faulting and folding have complicated the details of structure. One system of faults, trending nearly north and south, is responsible for a number of parallel, finger-like ridges. Faults of another important system extend N. 60° to 70° E. St. Thomas Gap has resulted from the dropping of a large irregular block or a number of adjacent blocks, and on the floor of the gap the rocks have been tilted by folding and faulting. Displacements on faults bounding the gap and affecting the adjacent highlands range from hundreds of feet to several thousand feet. In a plunging anticline near Mud Well the Overton and Horse Spring formations appear to be almost con-

formable on the Mesozoic rocks. Sawtooth Ridge is an overturned block of Kaibab limestone with local overthrust relations to younger formations. Apparently its structure is the result of intense local compression.

In general, faults do not seem to be continuous from the Muddy Mountains to the Virgin Range, but the Rogers Spring fault is a possible exception. The eastern boundary of the schist ridge northeast of St. Thomas is probably a fault, and it is directly in line with the monoclinal folding of the clays northeast of Bluepoint.

It is worthy of note that both faulting and folding appear to be much more intense in this region near the Plateaus than in known parts of the Basin Ranges farther west. Instead of a gradual dying out of the effects of deformation toward the east, those effects are intensified in a border zone, and the change to strata which are relatively little deformed appears abruptly, at a well defined line.

Physiography.

Old surfaces of aggradation and erosion.—In all of the wide intermontane valleys remnants of former aggradation surfaces are preserved as mesas, which usually have a capping of caliche, a firm conglomerate with a rich matrix of calcium carbonate or gypsum deposited on evaporation of ascending ground-water. The highest surface, represented by Mormon Mesa, lies 700 to 800 feet above present stream grades, and successively younger surfaces are 250, 100, and 40 feet above the streams. All of the surfaces are underlain by coarse gravel and sand to a depth ranging from a few feet to 300 feet. The two lower levels form narrow belts bordering streams, and may appropriately be termed terraces. The upper surfaces are much more extensive, and are not terraces in the ordinary sense of the term. Remnants of the highest surface show that it once extended through St. Thomas Gap and covered all of the area north of Callville Mountain except a few scattered peaks, and rock-cut benches bordering these higher points indicate that the base-level corresponding to the aggradation surface remained stationary for a considerable period. In Callville Mountain a distinct fall line marks the elevation at which the surface met the mountain walls. Many stream channels on the surface of the mountain have easy grades and comparatively wide

valleys, but near the edges of the block they plunge sharply by a succession of falls which total a height of 400 feet or more. The aggradation surface has a general slope conforming to the grades of the larger streams, and also slopes from the mountain walls toward the valley interiors. A considerable part of this highest surface was destroyed during the growth of the next one, which is locally 5 or 6 miles in width and connects with smooth benches cut on solid rock. The inner surfaces or terraces record comparatively short halts of base-level. Within relatively recent time both the Virgin River and Muddy Creek have incised their floodplains, which may properly be considered a third terrace level.

Outline of Geologic History.

In the Virgin Mountains the geologic record extends backward into pre-Cambrian time, but in the crystalline rocks the record is complicated and obscure. Apparently the clastic Cambrian sediments were deposited on a nearly even surface which cuts across the structure planes of the metamorphic rocks. During much of the Paleozoic era southeastern Nevada was part of the Cordilleran geosyncline, although it was east of the area which received the thickest sediments. Further study will be required to determine the amounts and kinds of sediments deposited previous to the Devonian period. The Upper Devonian sea shallowed to the east and deepened to the west and north. Earlier Devonian invasions may have covered the region, but faunal evidence is not available. Marine invasions occurred in both Lower and Upper Mississippian, in Pennsylvanian, and in Permian times. During the Permian and perhaps during the Upper Pennsylvanian, thick continental and littoral deposits accumulated under conditions of aridity or semi-aridity. At the close of the era the region was uplifted without perceptible tilting, and suffered moderate erosion.

The Californian Lower Triassic sea deposited limestone, gypsum, and clastic sediments, and a great thickness of continental deposits followed the retreat of the sea. An interval of erosion succeeded, and another epoch of continental sedimentation began with the deposition of the coarse Shinarump conglomerate. A thick series of sand,

silt, and clay was furnished by highlands which arose to the south, and the enormously thick and widespread Jurassic sandstones were probably derived from the same source. All of the Mesozoic sediments indicate aridity of climate. In post-Jurassic time the region suffered intense folding, accompanied by overthrusting, probably in connection with the Sierra Nevada disturbance. During the late Mesozoic and the first half of the Tertiary the Muddy Mountain area was probably part of a high region with exterior drainage, and received no deposits which have been preserved. Intense normal faulting occurred, and thick basin deposits were formed, probably in Upper Miocene time. After erosion had subdued the topography there was a recurrence of faulting which formed new basins, in which thick deposits of saline silts and clays accumulated. The present drainage system was established later, probably in Quaternary time, and since its establishment there have been changes of base-level amounting to several hundred feet. Comparatively recent disturbances have deformed late Tertiary and Quaternary deposits, and it is possible that considerable faulting accompanied these latest crustal movements.

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Art. V.—*The Stanley Shale of Oklahoma;* by C. W. Honess.

[By permission of C. W. Shannon, Director, Oklahoma Geological Survey, Norman, Oklahoma.]

Introduction.

Although the Stanley shale was not defined and named until 1902[1] the strata composing this formation have been known since the fore part of the 19th century, when the early explorers and travelers entered the regions of the outcroppings and wrote brief descriptions of the topography and described some of the exposures.[2, 3]

In January, 1857, the Arkansas Geological Survey was organized and D. D. Owen made State Geologist. His explorations and studies led him into all parts of the State and by 1860 his second report appeared, which had to do with the middle and southern counties of Arkansas, including the area of outcrop of the Stanley in that State. His work was of the nature of a reconnaissance, and his untimely death prevented his writing all of the report; nevertheless he succeeded in determining, at least to his own satisfaction, the general position in the geological column of the Jackfork and Stanley, both of which he assigned to the "sub-Carboniferous," *i. e.* "at least not lower than the base of the 'sub-Carboniferous' . . . . . and the highest and newest of this great series of sandstones, slates and shales not younger than the base of the true coal measures."[4]

Since his time several geologists have studied the Stanley both in Arkansas and in Oklahoma, notably J. A. Taff,[5] George H. Girty,[6] and H. D. Miser.[7]

[1] Taff, J. A.: Atoka Folio of the U. S. Geol. Survey, No. 79, page 4 ("from the village of Stanley in the Kiamitia Valley, where it is extensively exposed").

[2] Nuttall, Thos.: "A Journal of Travels into Arkansas Territory during the year 1819," etc., pp. 296, Philadelphia, 1821.

[3] Ward, J. A.: "A Geological Reconnaissance of the Arkansas River," Cincinnati, 1853.

[4] Owen, D. D.: 2nd Rept. of a Geological Reconnaissance of the middle and southern counties of Arkansas for 1859-60, pp. 13-153. Philadelphia, 1860.

[5] Taff, J. A.: Atoka Folio, No. 79, U. S. Geol. Survey, Atlas.

[6] Girty, Geo. H.: Fauna of the Caney Shale, U. S. Geol. Survey, Bull. 377.

[7] Miser, H. D.: Manganese Deposits of Caddo Gap and DeQueen Quadrangle. U. S. Geol. Survey Bull. 660-C.

ARKANSAS

R27E

R26E

R25E

R24E

NOTE.—In the Legend above, *Standley* should read *Stanley*.

Many of the details of the lithology, distribution and structure of the sediments have been worked out and facts regarding the origin and source of the beds and evidences of their age have accumulated, until it is believed a close approximation to the truth with respect to these matters is at hand. That the Stanley is either upper Mississippian or Lower Pottsvillian (lowermost Pennsylvanian) in age has for sometime been the opinion of David White[8] and most stratigraphers are in accord with this view.

During the four years just past it has been the privilege of the writer to pursue his own bent and his interests have led him into a field which involves the Stanley series. The area covered lies in southeastern Oklahoma (see index map) in the south-central part of the Massern Ranges ("Ouachita Mountains" of most writers), and the surface exposures range in age from doubtful Cambrian to Pennsylvanian. The succession of geological formations in this region is essentially the same as that in west-central Arkansas, where the same formations are exposed and where identically the same dynamic forces have operated. This succession has been worked out and briefly described by H. D. Miser[9] after years of painstaking study and labor in the DeQueen and Caddo Gap Quadrangles. In brief the complete section is as follows:

Generalized section of Paleozoic rocks in the Ouachita Mountain region of west-central Arkansas.

[From U. S. Geol. Survey, Bull. **691**, p. 272; by H. D. Miser.]

Carboniferous:	Feet.
Pennsylvanian:	
Atoka formation	6,000
Upper Mississippian:	
Jackfork sandstone	5,000-6,600
Stanley shale	6,000
Hot Springs sandstone	0-200
Unconformity.	
Devonian (upper part may possibly be Carboniferous):	
Arkansas novaculite	0-950
Unconformity (?)	
Silurian:	
Missouri Mountain slate	50-300
Unconformity (?)	
Blaylock sandstone	0-1,500

[8] Quotation in Fauna of Caney Shale, p. 8, U. S. Geol. Survey Bull. 377.
[9] Miser, H. D.: loc. cit.

	Feet.
Unconformity (?)	
Ordovician:	
Polk Creek shale	0-200
Bigfork chert	700
Womble shale	250-1,000
Blakely sandstone	0-500
Unconformity (?)	
Mazarn shale	1,000
Ordovician (?)	
Crystal Mountain sandstone	850
Unconformity.	
Cambrian:	
Collier shale (observed thickness)	200

A great many notes and other data have been secured bearing on the general geology of this whole section as exposed in Oklahoma but only the Stanley formation will be described here. The report, complete with photographs, maps and sections, will appear in due time as a bulletin of the Oklahoma Geological Survey. In the meantime my thanks are due to Dr. C. W. Shannon, Director of the State Survey, who made it possible for me to carry out these researches. I wish also to acknowledge my indebtedness to Dr. Charles Schuchert, who has critically read and corrected this manuscript.

The Stanley Shale.

The Stanley shale is exposed throughout the full extent of the Massern Ranges from Atoka, Oklahoma, to Little Rock, Arkansas, covering in all many hundreds of square miles of territory. That portion of the formation under discussion, which comes to the surface in the Lukfata Quadrangle on the flanks of the great anticlinorium has been studied with considerable care as have also certain areas adjacent to the north and to the west. A cursory examination was made of the sediments in the vicinity of Redden and east (northeast of Atoka in the Atoka Quadrangle) and a hurried trip made through the Kiamichi River valley (in the Antlers Quadrangle) but of the exposures in Arkansas the writer has seen only those occurring near the Oklahoma-Arkansas line—a strip about 10 miles wide. In the descriptions which follow, therefore, it should be understood that it is the region of the Lukfata Quadrangle in particular and the areas immediately adjacent to the north and west, a few miles in each case, to which the writer refers. His statements in no case are drawn from or concern any other area.

The Stanley shale formation in general is composed of materials which are non-resistant and when exposed to weathering and erosion are easily reduced to low rounded hills and ridges and intervening flats, and "glades." Good exposures of shales, slates, sandstones, and the other rocks composing this formation are, therefore, not very plentiful and such as do occur are unfortunately almost always interrupted at frequent intervals—the sandstones projecting, the shales covered. Along the creeks and rivers in favorable places, especially where streams flow across the strike of the rocks, partial sections of the strata present themselves to view, but elsewhere, on all the slopes and hill tops rarely does one see more than exfoliated bowlders of the hard sandstones or float from the thin-bedded materials.

Being a humid region trees and brush form a thick cover over most of the country and a mantle of rocky soil prevails on all the low slopes. The flats, where wet and low, often bear an impenetrable undergrowth of brambles, green-briers and thorns, but where higher and drier are sometimes grass covered and more or less open with a poor, blue clay soil.

The strata have been sharply folded, contorted and bent, over the entire region under discussion. Large and small drag folds are practically everywhere present, slickensided zones and slates have been developed in all the strata throughout the mass and faults of unknown displacement occur to such an extent that one never knows, except at the very bottom of the formation, where the Stanley lies upon the recognizable Arkansas Novaculite—whether what he is looking at is right side up or not or whether there be repetitions in the section. It is, in fact, impossible to find anywhere an undisturbed continuous and measurable section. Consequently, a determined thickness of the Stanley is not known and cannot in the Lukfata Quadrangle be calculated or estimated. The thickness elsewhere is stated by Taff and Miser to be approximately 6,000 feet. The writer has not attempted to measure the type section of the Stanley at Stanley, Oklahoma, but concurs in the belief that it must be at least as thick as that, and with a similar thickness in the area studied to the southeast.

The basal beds of the Stanley (in the Lukfata Quadrangle) are tough, hard, fine-grained, evenly bedded, blue-gray, stony flints, interbedded with a little hard, even

bedded, drab, slaty shale in layers one-half inch or less up to three inches thick and averaging one inch. Grading upward into thin-bedded, hard, fissile, blue, slaty shale uniformly and evenly bedded, the blue tough flints become less and less and practically cease at a horizon 65 feet above the bottom where a very characteristic thin quartzite (1 foot to 4 feet) occurs. This is cut by numerous 1 inch quartz veins traversing it in all directions; it is a resistant layer and forms a shelf or projecting ledge in many places and it is found from one end of the region to the other which is a very good indication of widespread (50 ×30 miles) conditions and persistence of beds. Dr. Schuchert thinks these basal 65 feet should join to the Arkansas Novaculite series, thus making the heavy bedded, light gray quartzite, the bottom of the Stanley.[10] The following is a measured section of the second and third divisions of the Arkansas Novaculite plus the succeeding basal beds of the Stanley as observed on Flat Rock Branch at the road crossing SE. ¼, sec. 17, T. 3S., R. 26E., Oklahoma.

Basal Beds of Stanley.

Top.		Feet.	Inches.
1.	Dark thin fissile shale weathering greenish to bronze, one or two thin quartzitic layers....	6	
2.	Light gray quartzite heavy bedded and cut with veins of milky quartz....................	3	6
3.	Light gray quartzite thin even quartz veins..		8
4.	Thin-bedded fissile blue slaty shale—evenly finely bedded now and then a harder quartzitic layer under two inches in thickness....	29	
5.	Thin-bedded fissile blue slaty shales uniformly and thin bedded, jointed; one inch layers quartzite occur not infrequently and are extremely hard and tough and of blue-gray color	32	
6.	Blue flinty layer..........................		3
7.	Hard even bedded drab slaty shale..........		11
8.	Hard blue flint layer......................		1
9.	Drab hard shale...........................		3
10.	Blue-gray flint layer......................		2
	Hard even bedded drab clay shales...........	1	2
11.	Uniformly bedded banded white flint, banded only at the bottom; top massive gray flint..	1	6

Upper Division Arkansas Novaculite.

12.	Concretionary resistant gray harsh novaculite weathers porous (calcareous) white and gritty	26	

[10] Personal correspondence.

		Feet.	Inches.
13.	Black flint	1	
14.	Bluish gray harsh novaculite with red tinge weathers lavender and finally to a cream-colored porous chert	11	
15.	Resistant blue quartzite, flinty film ½ inch thick	2	
16.	Blue-white translucent flint		6
17.	Concretionary massive schistose cream-colored porous chert (novaculite) weathers almost white	3	
	Middle Division Arkansas Novaculite.		
18.	Stony black chert (novaculite)	1	
19.	Coal-black shale, weathers to a brown clay shale, fissile hard, thin bedded	9	
20.	Coal-black shale and black flint (novaculite) thin bedded and concretionary	15	
21.	Thin-bedded (chiefly under 1 inch) black flints, few shales in bottom; vein quartz in upper 2 feet	12	
22.	Partially covered coal-black brittle slaty, flinty shale	16	
23.	Coal-black brittle slaty shale and black flint, seamed by minute quartz veins intricately intersecting	8	9
24.	Blue-black flints (novaculite) in layers 2 to 6 inches	9	
25.	Hard black flint and shaly seams in beds not over 2 inches	4	
26.	Hard black novaculite ledge		6
27.	Covered, probably black slaty shale	4	
28.	Hard black novaculite ledge		4
29.	Coal-black hard slaty shale	1	4
30.	Black flinty layer		3
31,	Shaly flinty layers, coal-black, up to 1 inch in thickness	2	
32.	Coal-black slaty shales and thin flinty layers		7
33.	Black pyritiferous flint		3
34.	Black slaty shale and a few 1 inch layers of black flint	3	
35.	Lenticle of thin-bedded shale pinching out		3
36.	Black even-bedded cherty layer		3
37.	Concretionary black flint undulating surfaces	2	3
38.	Thin, slaty black flints undulating		3
39.	A local intraformational conglomerate—a thoroughly cemented black flint with pebbles clearly outlined on both fresh and weathered specimens *thickness 6″* occurs at this horizon but was not found at this place.		
	Basal Division Arkansas Novaculite.		

Above the quartzite ledge, at the base of the Stanley, occur some siliceous shales and sandstones which are micaceous, ripple-marked, and cross-bedded. They are greenish gray in color when fresh but weather to a dingy, bronzy appearance upon exposure. There are, however, only a few feet of these and they are quickly followed by a considerable thickness, perhaps 200 feet or more of schistose, red, soft, sandstones and grits, the red color being due to oxidation. These are usually coarse to medium-grained, are often micaceous and seem to be developed best within the eastern half of the area mapped (see map).

A heavy bed of very resistant tuff intervenes at this place in the section whose thickness approximates 90 feet on Mountain Fork River, sec. 27, T. 2S., R. 25E. The material consists, for the most part, of fresh feldspars and resembles a coarse graywacke or arkose in the hand specimen but is in reality a volcanic ash. It is usually gray in color, flecked or mottled with green blotches of chlorite, but there are as many varieties and degrees of fineness and coarseness of this rock almost as one might collect specimens.

This tuff is a very important layer of rock, for it is the only recognizable horizon in the lowermost 3,000 feet of the Stanley and makes a good identifiable key ledge from the distribution of which it will be possible to decipher the major structural features of the lower part of this formation if they ever are to be made out.

That this rock is a tuff and not a graywacke or arkose of sedimentary origin, as has hitherto been supposed[11] was discovered by Dr. C. P. Berkey in 1917, when he reported to me in a letter the results of an examination of some rocks sent to him at the close of my first summer's work in the region.

In plane-polarized light, under the microscope, almost any of this material thus far examined may be seen plainly to be made up wholly or partially of angular fragments which are bounded by broadly curved concave lines meeting in sharp points, characteristic of volcanic ash fragments and known as "bogen structure." The majority of the fragments have devitrified and under crossed nicols these lose their identity in an aggregate of quartz,

[11] Miser, H. D.: loc. cit.

feldspar, sericite and other minerals masking the original structure. Angular lithic fragments of slate, pieces of limestone and sandstone of megascopic size are extremely common as xenoliths and occasionally one sees a piece of basalt in the tuffs. The feldspars are remarkably fresh in most specimens and are medium acid in composition, approximating that of oligoclase or oligoclase-andesine ordinarily. Chlorite occurs in noticeable amounts for the most part in large grains or blotches up to an inch in diameter.

The map accompanying this article gives all of the outcroppings of the Stanley tuffs in the Lukfata Quadrangle as they have been mapped by the writer—all the outcroppings having been located by pacing and checking on the section corners.

Following the tuff is a thick series, several hundred feet over all, of hard and soft thin-bedded sandstones, slates and shales, chiefly sandstones, which may be described as fine- and uniform-grained dark greenish gray sandstones, usually cross-bedded and often ripple-marked.

This completes what is estimated to be about the lower third of the formation.

Succeeding these sandstones and continuing well beyond the middle of the Stanley, black shales and slates become the predominating materials and instead of ridges and wooded slopes one finds bushy flats and glades where they outcrop. This transition to softer rock is not sudden nor are the shale masses entirely without sandstones. The latter cease gradually, and by degrees they become thinner and more irregular as time goes on until gritty sediments practically are wanting. The shales are all black or dark steel-blue in color and are well indurated. Cone-in-cone concretions characterize a portion of this subdivision of the Stanley and are found widespread geographically. The thickness of the shaly portion has not been estimated but there must be several hundred feet of the shales.

Passing upward one again encounters sandstones of the bluish gray, massive, hard, resistant variety interbedded with blue, hard clay shales, and these are succeeded by black cherty shales and thin-bedded black cherts and flints.

The black flints constitute a well-defined formation, in themselves, of about 25 feet thickness and were encoun-

tered repeatedly in outcrop all the way from Little River, sec. 34, T. 4S., R. 21E., east-northeast for 40 miles to sec. 21, T. 1S., R. 27E. The black flints are without organic remains and have not been found west of Little River.

The topmost 2,000 feet or so of the Stanley is a rather monotonous series of alternating, even fine-grained sandstones and sandy shales, thin-bedded, more or less ripple-marked and cross-bedded in the lower portion but becoming heavier bedded in the uppermost members and passing gradually, by transition, into the coarser sandstones and "millstone grits" of the Jackfork sandstone formation.

The writer succeeded in obtaining a succession of the uppermost beds including the transitional series and basal portion of the Jackfork in a place where there was no doubt as to the correct sequence of the deposits and this will be appended in condensed form. The succession occurs in the north central part of sec. 22, T. 1N., R. 26E. along Beech Creek.

Stanley-Jackfork Transition Series.

Section on Beech Creek, Sec. 22, T. 1N., R. 26E., Okla.

Beginning 400 paces west and 300 paces south of W.¼ cor. sec. 23, T. 1N., R. 26E.

Top.		Feet.	Inches.
38.	Gray sandstone thick-bedded, concluding the section 100 paces south and 36 paces south-east of the N.¼, cor. sec. 22, T. 1N., R. 26E.	14	6
37.	Covered, probably shale....................	12	
36.	Massive ledges fine-grained gray quartzitic sandstone	22	2
35.	Covered, probably shale....................	12	
34.	Massive and heavy bedded sandstones and quartzites	4	8
33.	Black carbonaceous shales and thin argillaceous sandstones	10	
32.	Sandy shales and thin sandstones interbedded with heavy massive ledges gray quartzite..	25	10
31.	Covered, probably a clay shale.............	20	
30.	Thin, gray, hard sandstones with sandy carbonaceous shale partings	10	5
29.	Massive gray sandstones and quartzites undulating but without shale partings, in beds one to ten feet........................	87	4
28.	Poorly exposed sandy shales and sandstones..	62	

		Feet.	Inches.
27.	Massive gray sandstone undulating in beds 1 to 6 feet, at bottom of which are *fossil plants, seeds and scales*	15	
26.	Resistant hard, gray sandstones and thick-bedded soft gray sandy shales, with *plant remains (collection No. 471)* at bottom	18	3
25.	Thin sandstones and sandy shales interbedded and undulating	12	8
	The approximate Stanley-Jackfork contact.		
24.	Sandy greenish grey shale and soft sandstone with fossil *plants at bottom (Collection Nos. 469-470)*	6	
23.	Greenish gray, soft sandstones, blue and black clay shales	3	6
22.	Massive ledges 1 to 6 feet thick, of blue-gray quartzitic sandstone undulating, no shales in partings	18	1
21.	Greenish gray quartzites and hard sandstones in beds 1 to 4 feet thick interbedded with blue clay shales in beds 1 foot to 7 feet	91	
20.	Covered	34	10
19.	Massive hard gray sandstones averaging 1 foot in thickness containing two thin clay shale partings	21	
18.	Light blue clay shales containing soft clay concretions, in part sandy	21	5
17.	Massive ledges of blue quartzite and quartzitic sandstones 1 to 4 feet in thickness with three or four thin (2 inch) shale partings.	22	4
16.	Mass of blue clay shale with thin layers of sandstone containing *fragments of plants*	9	6
15.	Soft blue clay shales including a few thin fine-grained greenish gray sandstones	50	6
14.	Covered, probably chiefly shale, calculated thickness	58	3
13.	Quartzitic sandstone ledges, massive, in beds 2 inches to 9 feet in thickness, containing one 2 inch shale parting	34	5
12.	Hard quartzitic greenish gray sandstones in beds 2 or more feet thick interbedded with shales, the softer materials all being covered. Calculated thickness, over all	695	3
11.	Resistant hard sandstones in beds 1 to 3 feet thick	21	2
10.	Fine-grained greenish gray soft sandstone		

		Feet.	Inches.
	containing *fossil plants, seeds, etc.* (*Collection No. 473*)		6
9.	Thin-bedded dark sandy shales and sandstones containing *fossil plants in two horizons*	7	
8.	Massive evenly bedded gray resistant sandstones in beds 1 to 11 feet thick	25	1
7.	Dark shales and thin dark sandstones partially covered	205	
6.	Massive gray hard sandstones, in part peculiarly cross-bedded and undulating	23	
5.	Shales and sandstones, not well exposed	12	
4.	Hard greenish gray sandstone with shale partings	7	6
3.	Blue soft clay shales somewhat sandy below.	48	
2.	Resistant massive blue quartzitic ledge	15	
1.	Fine-grained gray sandstones and soft dark green sandy shale	34	5
	Total thickness	1791	7

From the point where this section was concluded northward, higher in the series, the greater portion of the rocks is covered for some distance, certain hard ledges only being exposed to view. These materials, however, are seen to be of the same hard quartzite and resistant white or gray sandstone as occurs below, alternating with some dark clay shales and shaly sandstones, the mass as a whole forming a formidable mountain (Walnut Mountain) 2,100 feet high striking N. 70° E. many miles across the country.

Just what proportion of the Beech Creek section should be assigned to the Jackfork formation and what part to the Stanley is difficult to say. The two formations are conformable and continuous in deposition. In general the sandstones of the Stanley are dark greenish gray in color and fine-grained while those of the Jackfork proper are white and coarse-grained. On this basis one would be inclined to place most of the Beech Creek section in the Stanley, but certainly the uppermost 325 feet at any rate belong to the Jackfork. Farther west, T. 4S., R. 20E., one encounters the same difficulties of delimitation.

Paleontology.

Organic remains in the Stanley shale are indeed scarce. Why there should be so few in all this 6,000 feet

or more of sediments is surely not because there was no life nor does it seem that the dynamic forces operative in this region should have destroyed all traces of its existence. A few fossils have, however, been found, and the writer believes that continued search will reveal more.

A collection of plants including some ferns was collected from the upper Stanley in Arkansas a number of years ago (as referred to by Miser, U. S. Geol. Survey, Bull. 660-C, p. 66). The Beech Creek locality, sec. 22, T. 1N., R. 26E., Oklahoma, as indicated in the description above, has yielded fragments of plants including fern pinnules and some seeds in several horizons. The Jackfork sandstone above is at times quite replete with bits of wood and leaves. The writer has found great numbers of them all through the mountains from Atoka to Arkansas in the Jackfork but they are always so poorly preserved that little use can be made of them.

Somewhere in the Stanley (exact locality not known) two plants were discovered, Nos. 977 and 882, both poorly preserved.

At a point 450 paces east of the W.¼ cor. sec. 33, T. 4S., R. 21E., on the west bank of Little River near the middle of the Stanley close to the cone-in-cone horizon, were found two plants (numbers 941 and 942). In this same place on Little River in a tough coarse sandstone layer three inches thick, and in the same outcrop, but not the same horizon, with the plants the writer found also a small marine fauna—so far as known the first animals ever found in the Stanley. These consisted of bryozoa and brachiopods and great numbers of crinoid stems for the most part, collectively numbered as specimens 943 and 944.

Near the bottom of the Stanley (within about 25 feet of the bottom) in the exact center of sec. 27, T. 2S., R. 24E. were found a few specimens of an inarticulate brachiopod No. 1015, and the same horizon was located also 4 miles to the east at a point 275 paces (2,000 paces per mile) south of the center of sec. 29, T. 2S., R. 25E., where three or four more specimens of the same brachiopod were found. (No. 1016.) These occur in a hard pinkish white fine-grained sandstone.

It remains to mention one other occurrence of fossils—a rather unusual one—and that is the presence of crin-

oidal fragments embedded in the tuff in the lower part of the Stanley.

The fossil plants, poor though the materials are, were all sent to Dr. David White of the U. S. Geological Survey for identification and interpretation; the fossil shells and other animals were submitted to Dr. Charles Schuchert of Yale University who in turn showed them to Dr. Ulrich of the U. S. Geological Survey. Dr. White has not yet reported on the plants from the Beech Creek locality but concerning the others he says:

"No. 941 is a specimen representing a portion of a Lepidodendron trunk. It is, however, partially decorticated and therefore is not specifically determinable.

"No. 942 is a wholly decorticated Lepidodendroid stem, in which the nerve traces are very obscurely indicated. It may be either Lepidodendron or, more likely, Bothrodendron.

"No. 977. This number is given to two Calamarion fragments, each of which contains a complete internode. The rock has been so crushed and the stem fragments so deformed that it is impossible to say with confidence whether either of the stems belong to Astrocalamites. Both might belong to Calamites.

"No. 882 is a fragment of a fern frond, bearing slender pinnæ of some Sphenopteris. The fragment is so weathered as to show only the topography and dim outlines of the pinnules, the nervation and borders of which cannot be clearly discerned.

"These specimens, I am sorry to say, are none of them specifically determinable. Therefore, any conclusion as to the age of the beds must rest on inferences based upon the general aspect or facies of the decorticated or badly worn and deformed fragments.

"The phyllotaxy of the Lepidodendron indicates a relatively ancient Carboniferous type. One of the Calamarian fragments is more suggestive of Asterocalamites than Calamites. The Sphenopteris may belong to a group found in the upper part of the Mississippian and in the very old Pennsylvanian.

"The collection does not contain anything specifically identifiable with any form characteristic either of the Mississippian or Pennsylvanian. It appears, however, to harmonize with other material collected by Ulrich, Miser and myself from the Stanley or Jackfork of Oklahoma and western Arkansas, none of which is really satisfactory, since all the fossils are very fragmentary and have generally been rubbed or deformed in the course of depositions in gritty rock. After examining your specimens the tentative conclusion that the Stanley represents either very late Mississippian, possibly upper Chester, or Pennsylvanian of earlier date than I am acquainted with in the Appalachian trough, is slightly stronger."

With regard to the small marine fauna found on the banks of Little River (specimens 943 and 944) and the inarticulates from the base of the Stanley (specimens 1015 and 1016) Professor Schuchert writes as follows:

"It seems to me fairly certain that these specimens cannot be other than either Mississippian or Pennsylvanian. As you got an undoubted Lepidodendron even beneath lots 943 and 944 and as the specimen appears to me like a Pennsylvanian form, it seems that the whole of the Stanley and Jackfork may be Pennsylvanian in age rather than Mississippian. The marine fossils do not indicate anything to the contrary. Your marine fossils are as follows:

Orbiculoidea nitida Phillips. Loc. 1015 and 1016.

I cannot distinguish the specimens from Coal Measures forms.

Crinoid columnals. Loc. 943 and 944. Common. At least two species.

Cystodictya sp. undet. Loc. 943 and 944.

Rhombopora, sp. undet. Loc. 944.

Fenestella, sp. undet. Loc. 944.

Undet. Bryozoa. Common Loc. 944.

Productus suggesting *Pustula nebraskensis,* Loc. 943 and 944.

Chonetes, sp. undet. Loc. 943.

Very fragmentary. Finely striate form.

Fish bone. Loc. 943.

Dr. Ulrich reports as follows:

"Frankly speaking, these Stanley remains are certainly a poor lot—not at all noisy in imparting information. Only the *Orbiculoidea nitida* which identification seems as good as can be made with the material, is in sufficiently good condition to warrant a definite opinion.

"The finely pustulated fragments of brachiopods I believe to belong to a species of *Chonetes.* As all the fragments expose the inner surface of the valves I deduce that the exterior is distinctly striated. But whether it is most like Mississippian or Pennsylvanian types one can hardly say. Still as the striated Mississippian species of *Chonetes* are practically confined to beds older than the Warsaw and as it is almost too much to concede that the Stanley can be Lower Mississippian, then these fragments may be said to point toward the Pennsylvanian rather than Mississippian.

"The Bryozoa also are too imperfect for satisfactory determination. And yet they are not quite hopeless. There is a fragment of *Fenestella.* This says nothing. Then there are a couple of branching specimens concerning which I cannot decide

whether they should be called *Rhombopora* or *Batostomella*. These also throw no light on the question.

"But the fragments of *Cystodictya* suggest Chester and Lower Pennsylvania species rather than older species of the genus.

"Finally there are two fragments that seem to belong to *Prismopora,* a genus ranging from Mid. Devonian to Pennsylvanian. Because of their smallness these Stanley specimens suggest *P. minuta,* a Middle to Upper Pennsylvania species in Illinois.

"The invertebrate part of the evidence by itself would not be conclusive either way. The trend of the evidence is toward the Pennsylvanian rather than the Mississippian (either early or late). Again there is nothing in the collection that may be justly cited as definitely opposed to correlation of the Stanley with lower Pottsville or basal Morrow, which conclusion I reached in my "Revision" mainly on physical and diastrophic consideration.

"The fossils observed by me in the Jackfork seemed decidedly corroborative of my convictions respecting the post Chester age of the Stanley. So far as I can see your new evidence leaves the problem just about where I left it in 1911—that is, with the probabilities favoring assignment of the Stanley to the earliest Pennsylvanian."

Origin of the Stanley Shale.

The outstanding facts with regard to the sedimentation of the Stanley are: (1) the dark color of all of the shales, slates, and sandstones; (2) the uniform even fine grain of the sandstones and quartzites; (3) the total absence of limestones and of calcareous cements in the sandstones; (4) the tremendous thickness of the series; (5) the ripple-marked and cross-bedded structure of nearly all of the strata, sandstones and shales alike. Whatever the theory for the origin and source of these beds the above facts must be accounted for. Without arguing the various possibilities and impossibilities of such an accumulation, the writer wishes only to state that the conditions involved appear to him to have been essentially a gradually subsiding area into which a large river throughout the subsiding period discharged its load. How large the basin of subsidence could have been, how well-defined and what the shape of it was, are only matters of conjecture with him. That the inflowing river, which discharged its sediments into the bay or basin, was large is attested by the absence of all conglomerates and coarse sands, and by the silty nature of the deposits from top to

bottom of the Stanley—a silt which was more sandy at certain periods than others by reason of the well-known conditions controlling all large rivers, and one which was rich in organic matter at all times.

The ripple marks, rill marks, and cross-bedding throughout the succession would indicate that mud flats were repeatedly if not almost continuously a feature of the delta on which the ancient river laid these sediments. The silts, sands, and muds were evidently washed around and shifted about on the flats, re-sorted and finally deposited in the ripple-marked and cross-bedded condition in which we find them.

That fragments of plants, pieces of wood, bark, leaves, etc., should be washed down a river and become buried in the sands is, of course, a well-known fact and in accord with the facts of the Stanley sediments.

It should also be expected that a great delta deposit at the mouth of a large river such as it appears the Stanley must have been would from time to time, especially during periods of storms and rough sea, be peopled by marine animals. These doubtless would not move voluntarily from their habitats to fresh water but might easily be washed along by littoral currents and heaved shoreward by storm waves. Thus one may account for the few brachiopods and other animals found. With reference to the bryozoa and other fossils found at the Little River locality special mention should be made of the fact that this fauna occurs in a horizon about 3 inches thick composed chiefly of quartz gravel whose grains average about 2 mm. and that the fossils are broken to bits. Regarding the character of this fossiliferous layer Professor Schuchert says:

"The physical character of the rock of localities 943 and 944 leads me to the following physiographic and geologic conclusion. The material came in the main from a granitic country, though I think there were present also metamorphic rocks, for there appears to be present considerable micaceous schist. This schist is still in angular pieces and larger than the quartz pebbles, indicating shorter transportation. In addition, there is much black shale present, some of which is also metamorphosed but apparently not all of it. The quartz pebbles are fairly well rounded and with the sand appear to have come a much longer distance than the shale and schist. There are also rounded pieces of garnet present."

At no other horizon in the entire Stanley, excepting the tuff, is there so coarse a material.

Higher in the Stanley where the plant horizons were found, and in the Jackfork sandstones above, the vegetal remains occur in thin beds charged with small twigs and other small plant fragments, and also as scattered individual specimens. The latter are usually large, pieces of limbs and logs, but in all cases are macerated and eroded fragments—materials, it appears, which have been floated down stream from land areas to the south and southeast and out upon the delta to the north where they were engulfed in the sands.

Columbia University, June, 1920.

Art. VI.—*Popocatepetl again in Activity;* by Paul Waitz.

For some months we have seen from Mexico City on clear days of the rainy season that small eruption clouds were rising in puffs from Popocatepetl. This was a rather unusual spectacle, as since 1720, the year in which the last historically confirmed eruption occurred, the volcano apparently has shown only a very slight activity of fumaroles and solfataras. The long duration of this year's rainy season was not favorable for an investigation of the state of the mountain. As soon as better weather promised to allow of a successful ascension I gladly accepted the invitation of the Sociedad Cientifica "Antonio Alzate" to study the volcano. After careful preparation for the excursion I began the ascent in the company of some friends on the 10th of October of the present year; favored by wonderful weather conditions and good luck, the excursion had the very best of success.

We started from Amecameca (2532 m. above sea-level) on horseback at noon and after a five hours' ride through beautiful forests at sundown, reached Tlamacas, a locality situated on the north slope of the volcanic cone at a height of about 4000 m. above sea-level. The ranch house which years ago stood there at the side of a small hut used for sulphur smelting, had long since been destroyed by the revolution, but we found a few huts made of logs and covered with zacate-grass, which offered us a good shelter.

After a rather uncomfortable night on account of the low temperature, we started on the 11th of October at 4 A. M. on horseback from Tlamacas and rode as far as Las Cruces (about 4500 m.) from which point the horses were sent back to Tlamacas. From here on we made use of a fairly good zigzag trail which had been constructed last winter by the sulphur diggers (*azufreros*): a proof that in the past winter no snow lay on the slope of the mountain, although in former years a cover of snow used to reach down to Las Cruces. While this cover of snow has disappeared almost entirely, the glacier of the volcano, which formerly on account of the thick cover of snow could not be observed at all, is still well preserved. This glacier lies in a depression between the main cone and a prominent promontory, the Pico del Fraile, and has been preserved up to the present date because the

FIG. 1.—The crater of Popocatepetl on October 11, 1920, as seen from the lowest level of the crater rim. The west wall and the andesite porphyry in the background.

main cone is especially thick on this side and a very special kind of stratification diminishes the velocity of propagation of the heat waves from the depth toward the surface. The glacier reaches from the main summit, the Pico Mayor of the volcano (5450 m.), on the northwest slope of the cone, down to about 4800 m. We also found on the north side of the cone the side which was used for the ascent, small patches of snow in the depressions where it had been accumulated by the wind. On the east, south and west slopes the cone was entirely free from snow.

I arrived at the lowest part of the crater rim at 9:30 A. M. During the interval before my friends could join me I was able to study the crater and observe a rather strong eruption. At 11 o'clock we began to ascend on the rim of the crater, climbing along its east and south side in order to reach the highest point lying on the west side, where we arrived at 2 P. M. We climbed down on the other side of the crater rim until we again reached its lowest portion and from there went quickly down to Las Cruces and Tlamacas. Here we remained a second night and after having been able to observe and photograph a very strong eruption at 7 o'clock, the next morning we rode to Amecameca, and returned to Mexico City, where we arrived on the evening of the same day.

With the exception of the disappearance of the snow cover, the form of the mountain has not changed since the beginning of its new stage of activity. The crater also has preserved its form and figure, at least no considerable changes could be observed, and comparing the pictures of the crater which I made in 1905 with those taken on the present trip, I cannot find any changes. This does not apply, however, to the bottom of the crater. As long ago as 1895, Aguilera and Ordoñez, who at that time studied the mountain and measured the crater, remaining at its bottom for several days, described in its lowest portion a small lagoon, which was also well known to all those who had ascended Popocatepetl during the last 20 or 30 years. This lagoon has disappeared and in its place, but of much greater dimensions, I found an elliptical accumulation of andesite bowlders. This hill has a NW-SE longitudinal axis about 100 m. long, a transverse axis about 75 m. wide, and a height of 40 to 50 m. There is no doubt that this hill of black andesite bowlders is the upper part of a lava plug which after the

FIG. 2.—Cauliflower clouds of a steam eruption of Popocatepetl, October 12, 1920.

last lava eruption of the volcano fell back into the chimney and which during the two centuries of little activity on the part of the volcano lay buried under the débris of the crater walls and later on under a lagoon. The recent activity of the volcanic focus has pressed the plug slowly upward, and if, as seems probable, this activity should continue to increase, we may perhaps be able to observe the formation of a Pelée-needle within the crater of the volcano. But it is more probable that the course of events will be similar to those which we have been able to study on the volcano of Colima, where we have observed that during the course of nearly a century the formerly deep crater has been slowly filled up to the rim with block-lava.

We had the opportunity to observe that all the steam explosions which occurred in separate puffs during our stay on the crater, had their origin between the plug and the crater walls, while the plug itself showed no development of steam. Later visitors to the volcano, among whom was a gentleman who had accompanied me on my excursion, believed they were able to observe, on the first of November, that the plug meanwhile had been raised still farther, and that isolated emanations of steam now occurred also within its mass, and, judging from the yellow color, emanations of sulphur also.

From time to time the steam explosions (with the steam there is always mixed some sulphur dioxide (SO_2)) seem to throw up sand and ashes; we have been able to observe fresh accumulations of this material on the lowest portion of the crater rim and in these deposits the traces of larger stones also, which cannot very well be called bombs, because they were not of freshly molten material.

The steam explosions are connected with very strong, thunder-like noise, which can be very well heard as far as Tlamacas at least. Strong eruptions throw the steam out above the crater rim in thick clouds, which on account of their whirling movement take the form of cauliflower clouds. The explosion which we observed from Tlamacas on the 12th of October at 7 A. M., rose at least 500 m. above the highest point. We could not observe any kind of earthquake during the eruption, even in cases of strong explosions, and standing at the crater rim itself. Smaller eruptions of steam generally disperse within the wide crater, the longitudinal axis of which is, according to the

measurements of Aguilera and Ordoñez, 600 m. (nearly E-W), while the smaller axis has a length of 400 m., a depth from the highest point of 500 m., and from the lowest portion of the rim 250 m. During the pauses between the rather infrequent steam explosions one hears only the whistling of the fumaroles and the solfataras, which produce a noise similar to that of a number of steam engines blowing off steam at the same time.

Two of these solfataras in particular were known to me from my former ascension of the crater in 1905; they do not originate in the bottom of the crater, but lie in the lower portion of the crater walls in the southeast and southwest portion, and therefore have not yet been covered by the mass of bowlders of the plug, the form of which probably corresponds to that of the chimney.

It is too early to prophecy anything about the further development of the activity of Popocatepetl. If the observation said to have been made during the excursion on the first of November should prove to be exact, and the plug had been rising during the fourteen days since my ascent and investigation, for about 20 to 30 m., as those gentlemen state, then we may assume that the activity of the volcano is increasing. This we can conclude also from the development of steam, which is becoming continuously stronger. We cannot expect to see a Pelée-needle rising from the crater, with its depth of 500 m. as was mentioned above, but we can expect that the crater will become filled slowly with solid block-lava, produced by the breaking up and dismemberment of the column of solid andesite which fills the chimney. Of course not only years, but tens of years or even a whole century, may pass before the mass of bowlders fills the whole crater. Yet before the whole crater will be filled with these masses another event may take place as has been the case in the volcano of Colima, where in 1869 an adventitious cone with a double summit was formed which produced a small lava stream. For the formation of such a lateral adventitious cone the east and south sides of Popocatepetl are especially predestined, as they are characterized by a particular thinness of the crater wall.

Finally, there exists another possibility: The explosive power of the focus, be it through endogene processes in the magma or be it through the accumulation of pressure due to a casual closing of the emanation channels still open at the present time through the immense masses of

bowlders slowly accumulating in the crater, may be so far increased that it will be able to throw the contents of the crater into the air by a single formidable eruption. In this case we have to expect and to fear the occurrence of glowing clouds (Glutwolken, nuées ardentes). We have had an opportunity to observe and to study this phenomenon also on the volcano of Colima. There in 1913 the contents filling the entire crater up to the rim, as well as the mass filling the chimney to a great depth, and even the upper 150 m. of the crater cone, were thrown into the air by one single eruption and blown into dust partly by the explosion itself, partly by the fall of the masses on the cone and into the crater. Glowing clouds rolled down the flanks of the cone for several days and accumulated in the barrancas at the foot, where they flowed to a distance of about 12 km. from the crater.

Fortunately the Mexican volcanoes are not inhabited (within a radius of 10 km. around the summit of Popocatepetl we do not find a single inhabited place and towns do not exist within a radius of 15 km.); and the country furrowed by deep barrancas around the volcano would place strong obstacles in the way of lava streams and glowing clouds; therefore even a very highly increased activity of Popocatepetl would not have to be feared. Greater damage could be caused by extraordinarily strong eruptions of ashes, as the flat roofs used in this part of the country would not resist the weight of heavy masses of ashes.

MEXICO, November, 1920.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *A Revision of the Atomic Weight of Aluminium.*—Theodore W. Richards and Henry Krepelka have published a preliminary paper upon the atomic weight of aluminium, giving the results of four determinations based upon the ratio of aluminium bromide to the silver required to combine with the bromine in it. The preparation and purification of the aluminium bromide was carried out in a most ingenious and evidently perfectly effective apparatus, and all the details and whole process were carried out with the greatest care and skill, such as is always shown in the atomic weight determinations directed by Richards. The results, based upon bromine as 79.916 and silver as 107.88, are 26.967, 26.965, 26.956 and 26.954. The average is 26.960, while the result calculated from the total weights employed—nearly sixteen grams of the bromide and over nineteen grams of silver—is 26.963. The agreement of the results is remarkably close.

The usually accepted atomic weight of aluminium, 27.1, is based chiefly on the work of Mallet, published in 1880. This work has been highly regarded because results by three distinct methods agreed closely, so that the more recent result, in 1897, of Thomsen, 26.99, based upon a single method, was not accepted by the international committee. The new result is not far from that of Thomsen, and it appears probable that future work will not change it to any considerable extent. It seems certain, therefore, that the atomic weight of aluminium is slightly less than 27, and this is a matter of interest to those who are studying the structure of atoms and their numerical relations.—*Jour. Amer. Chem. Soc.*, **42**, 2221. H. L. W.

2. *The Chemists' Year Book, 1920;* Edited by F. W. Atack. Fifth edition, 16mo, pp. 1136. Two volumes. New York, 1920 (Longmans, Green & Co. Price $7.00 net).—The appearance in 1915 of the first edition of this work of English origin was due to the cutting off of the supply of German pocket-books which had been previously used by many chemists and other scientific workers. As it appears in its fifth year the book shows a vast amount of useful, well-arranged information, and it may be regarded as an improvement upon the German hand-books as well as a further convenience in its language to English-speaking chemists. It is well printed upon very thin paper of excellent quality so that it is very legible, while its bulk is small in comparison with its large number of pages. There are many tables, among which may be mentioned those giving gravimetric factors, five figure logarithms, specific gravities, solubilities, and the very extensive ones dealing with the properties of inorganic and of organic substances, and of minerals. There are also tables re-

lating to oils, fats and waxes, as well as to essential oils, alkaloids, synthetic dye stuffs, and drugs. Much valuable information is given in regard to analytical processes, including many technical tests and quantitative determinations. H. L. W.

3. *Dictionary of Explosives;* by ARTHUR MARSHALL. 8vo, pp. 159. Philadelphia, 1920 (P. Blakiston's Son & Co.).—This book in its main part gives an alphabetical list of the special and proprietary names of explosives with descriptions of their character, and in a great many cases their percentage compositions. There are more than 400 names in the list. There is a preliminary classification of the names according to the applications of the products in coal mining, blasting, as high explosives and as propellants. There is a final index of constituents where the names of the explosives containing each constituent are given. The book is of interest in showing the astonishing development of explosives in recent times, and in explaining the compositions of these materials. H. L. W.

4. *Catalysis and its Industrial Applications;* by E. JOBLING. 12mo, pp. 144. Philadelphia, 1920 (P. Blakiston's Son & Co.).—This little book from England, in its second edition, gives a very clear and impressive account of the exceedingly important application of foreign substances for the purpose of facilitating chemical reactions. There is a good introductory chapter dealing with general principles, then the industrial applications of catalysis are well discussed in connection with sulphuric acid and chlorine manufacture, the fixation of atmospheric nitrogen, the hydrogenation of oils, and many other processes. There are given many references to the literature. H. L. W.

5. *American Lubricants;* by L. B. LOCKHART. 8vo, pp. 341. Easton, Pa., 1920 (The Chemical Publishing Company).—This is the second edition, revised and enlarged, of a book designed particularly as an aid to the user of lubricants. The refining of petroleum is described, the theories of friction and lubrication are satisfactorily discussed, the applications of lubricants in many special cases are taken up, the physical and chemical testing of lubricants are described, and many specifications are given. The subject is very well and thoroughly treated. H. L. W.

6. *Fuel Oil in Industry;* by STEPHEN O. ANDROS. 8vo, pp. 244. Chicago, 1920 (The Shaw Publishing Company).—This book gives a good account of an important subject. The application of fuel oil in various industries is described, many useful tables and interesting statistics are presented, and these are 107 illustrations, including diagrams of apparatus and many reproductions of excellent photographs. The book is to be highly recommended to those interested in the subject. H. L. W.

7. *Spectra of Isotopes.*—Previous investigations by spectroscopic methods have indicated that the wave length of the brightest line $\lambda = 4058A$ of ordinary lead differs by a small fraction of a unit from that of lead of radioactive origin, but the amount was

too near the limit of detection by this method to make the result very certain. T. R. MERTON has now developed a new method in which a ring system of interference fringes is photographed on a plate so that they may be measured by a micrometer. In order to take account of variations in the diameter of the rings which would result from changes of temperature in the interferometer, or a shift in the position of the source of the light due to wandering of the arc which was used, the lead under study was alloyed with cadmium. In this way a comparison system of fringes was recorded which would indicate any variation in the difference of path between different plates whether due to temperature changes or alteration of the arc, and serve to correct the other lines. In carrying out the observations, if two specimens of lead emitted different wave lengths it could be noted what fraction of the distance between fringes any fringe was displaced. The sensitiveness of the apparatus may be judged from the alteration of the wave length which was necessary to shift the pattern by a whole fringe. This difference of wave length amounted to 0.084A in the lead line $\lambda = 4058$A and 0.146A in the thallium line $\lambda = 5350$A. Three specimens of lead were examined: (1) a pure sample of ordinary lead; (2) lead extracted from Joachimsthal pitchblende residues; (3) lead extracted from Ceylon thorite. The author's conclusions may be thus stated for the line $\lambda = 4058$A:

$$\lambda \text{ (lead from pitchblende)} - \lambda \text{ (ordinary lead)} = .0050\text{A} \pm .0007\text{A}$$

$$\lambda \text{ (ordinary lead)} - \lambda \text{ (thorite lead)} = .0022\text{A} \pm .0008\text{A}$$

which indicates that these substances are arranged in the order of their atomic weights. Further experiments were made on thallium using the line $\lambda = 5350$A, which indicated that

$$\lambda \text{ (ordinary thallium)} - \lambda \text{ (thallium from pitchblende)} = .0055\text{A} \pm .0010\text{A}.$$

The result for thallium does not command quite the weight of those for lead for it was not possible to isolate the pitchblende specimen, but it does seem to indicate that the thallium of pitchblende is an isotope of greater atomic weight than ordinary thallium.—*Proc. Roy. Soc. London*, **96**, 388, 1920. F. E. B.

8. *Magnetic Susceptibilities of Low Order.*—In carrying out the new magnetic survey of the British Isles some instrument was required capable of measuring the susceptibilities of various rock specimens. This need was met by the apparatus devised by ERNEST WILSON, in which the pull exerted by the magnetic field of a specially designed electromagnet on the specimen was balanced against the torsion of a phosphor bronze strip.

After a careful determination of the instrumental constant the author measured the susceptibilities of a considerable variety of rocks either worked into the form of a rod or after they had been

powdered and closely packed in a glass tube. Particular attention was devoted to different varieties of mica, tourmaline, and some of the aluminum alloys.—*Proc. Roy. Soc. London,* **96,** 429, 1920. F. E. B.

9. *The Airplane;* by FREDERICK BEDELL. Pp. VIII, 257. New York, 1920 (D. Van Nostrand Company; $3.00 net).—This volume is a development from the author's experience in preparing courses for Schools of Military Aeronautics, and is in fact an extension of his previous works entitled *Airplane Characteristics,* and *The Air Propeller.* It may be described as a reasonably complete text of airplane performance, with sufficient theory to guide the experimenter and designer and to provide the general reader, whose aim is educational or scientific, with an accurate statement of how sustentation and stability of flight are secured.

The mathematics of the book does not go beyond the simple algebraic equations of mechanics which involve the forces of weight and fluid resistance, restoring couples, and applied power. The complex and more or less obscure relations between the variables, or their dependence upon empirical constants (parameters) are clearly illustrated by a large number of diagrams.

Six of the chapters, which treat of, sustentation, wing and parasite resistance, thrust and power, have been previously published in the books above named. The seven new chapters discuss the more general topics of airplane performance at different altitudes, longitudinal, lateral, and directional stability, climbing, gliding, and structural features connected with the number of planes, the keel, the rudder, and the controls.

Among the men in this country who have attempted to develop the physical principles involved in flying and sought to codify them for the benefit of science PROFESSOR BEDELL holds a prominent place, and his success in presenting them will be recognized by the reader of this book. It is provided with a glossary of the terminology of aviation and an excellent index but the draughtsmanship and reproduction of the figures is unworthy of the publishers. A conspicuous lack is the absence of any reference to the literature of aviation either American or foreign. F. E. B.

10. *A Field and Laboratory Guide in Physical Nature Study;* by ELLIOT R. DOWNING. Pp. 109. Chicago, 1920 (University of Chicago Press).—This is a loose leaf text- and note-book for use in teacher training classes and normal schools. Its aim is to bring the pupil into contact with elementary scientific facts and phenomena and present them in such form that they will suggest problems inviting further study. One chapter treats of common rocks and minerals and their classification into various categories. Another suggests simple and interesting observations to be made upon the constellations or the sun and moon. The nine remaining chapters of the work are devoted to the construction of vari-

ous kinds of apparatus which are virtually toys in their simplicity but illustrate in an interesting way many fundamental physical principles. Elementary science teachers should find this a valuable source book for the preparation of their lessons.

F. E. B.

11, *Annuaire pour l'An* 1920; pp. VIII, 708, Appendices A.27, B.64, C.70. Paris 1920 (Gauthier-Villars et Cie.).—This annual publication of the *Bureau des Longitudes* has appeared without interruption since 1796. In all volumes of the series the material is arranged under five grand divisions with the following captions: The Calendar, The Earth, Astronomy, Weights and Measures. The fifth division alternates between two headings. In the even years it includes Physical and Chemical data and in the odd years it is devoted to geographical statistics and tables of annuities, of interest,'and of the expectation of life.

Chapters 1 and 3 contain extended ephemerides of the sun, moon, planets and stars for the meridian of Paris, tide tables, and a discussion of various calendars. A complete almanach for 1921 is added in a supplement. Chapter 2 shows the form, dimensions and density of the earth, together with tables of the acceleration of weight and the constants of terrestrial magnetism. Chapter 4 exhibits the various systems of weights and measures in their relation to the metric system, and the monetary systems of the world. Chapter 5 supplies a great variety of physical and chemical constants which cannot be briefly summarized. The leading tables deal with density, expansion, wave lengths, heats of combination and atomic weights.

Appendix A is an article on the prediction of swell, that is, the propagation of waves which persist after the wind has fallen. Appendix B discusses a new system of legal units. Appendix C contains a carefully arranged index which also carries references to the most important tables published in the five preceding volumes.

This book cannot fail to be a valuable addition to any reference library.

F. E. B.

II. Geology.

1. *Der Südrand der Puna de Atacama (NW-Argentinien). Ein Beitrag zur Kenntniss des Andinen Gebirgstypus und zu der Frage der Gebirgsbildung;* von Prof. Dr. Walther Penck, Abhandl. Sächs. Akad. Wiss. math-phys. Klasse, **37,** 1920, 420 pages, with a bibliography of 148 titles, 33 small but excellent photographs on 9 plates, 18 cross-sections, and a large folded map, 1:200,000, covering an area of 100 by 125 kil. with sketched contours at 100-meter intervals and geological colors distinguishing 52 formations.--The young author of this study, the son of Prof. Albr. Penck of Berlin, has won his spurs by painstaking exploration in northwestern Argentina as assistant on the geolog-

ical survey of that country during two years preceding the Great War. The report appears to have been written in Constantinople, as the author was professor in a university temporarily established there by the Germans during the war, and the preface is dated in that city in the summer of 1918. He is now professor of geology in the University of Leipzig. The text opens with a geographical description of a group of Andine ranges which enclose the bolson, or intermont basin, of Fiambala in the province of Catamarca. Two chapters then treat the rocks of the region in order of age; a fourth chapter discusses Andine structure; a fifth takes up the structural deformation of the region and its vulcanism, and a sixth treats the morphological evolution of the highland margin. Studies of mountain structure and origin have often been made elsewhere; but it is rare to find so careful an account of the origin and form of an intermont basin as is here given. W. M. D.

2. *Der Selpausselka;* von L. Leiviskä. Fennia, **40**, 1920. 389 pages, many maps and profiles, and 148 half-page photo-plates.—This elaborate monograph, the product of ten years of field-work on the two parallel morainic belts that traverse southern Finland, is to be highly commended for its truly scientific method. It first describes the features of each ridge with much care giving many references to profiles, large-scale detailed maps, and photo-plates; then generalizes the features thus described; and finally presents a critical inquiry into the origin of the belts and their relation to the sea in which the proglacial land area was submerged as the ice sheet withdrew. The chief conclusion is that the local plateaus, narrow ridges, or groups of hills, of which the belts are composed, were formed largely by the outwash of many small streams during pauses in the retreat of the ice sheet. W. M. D.

3. *De marine Kridtaflejringer i Vestgrønland og deres Fauna;* by J. P. J. Ravn. Meddelelser om Grõnland, vol. **56**, pt. 9, pp. 313-366, pl. 5-9, 1918.—This important paper, unfortunately in Danish, is the result of a critical study of the Cretaceous marine invertebrates from western Greenland. Fifty-four species are described. Fourteen of these are new and are referred to the genera Pecten, Lucina, Modiolaria (?), Limopsis, Axinus, Dentalium, Cadulus, Margarita (?), Atlanta, Bulla and Cyclichna. Ravn comes to substantially the same results as de Loriol, whose study of this fauna was published by Heer in 1882, and followed by Stanton in working over the material collected by White and Schuchert in that region. Ravn considers the Patoot fauna as corresponding to that of the Fox Hills of the western States. He is inclined to also refer the Ata fauna (Atane beds) to our Montana Group, but states that the evidence is not so good as in the case of the Patoot fauna. All are regarded as of Senonian age. Unfortunately only 31 of the 54 species are well preserved and capable of accurate identification, and he states that there is

probably a mixing of levels and possibly also of Museum labels. Thirteen of the Greenland forms are considered to be identical with Pierre and Fox Hills species, and only three—an Actæon and two Foraminifera, are common to the Atlantic Coastal Plain Cretaceous. Either this resemblance to our Western Interior Cretaceous and lack of similarity to the Coastal Plain Cretaceous is more apparent than real, or else some links in the chain of distribution should eventually turn up somewhere in the Arctic Archipelago. It may well be that a seaway extended westward from Disko Island instead of there having been any connection with the Atlantic, as has usually been supposed. The large number of West Greenland land plants found in our Coastal Plain Cretaceous may be considered as pointing in the same direction.

The present paper does not, unfortunately, settle the vexed question of age. Heer described four large fossil floras from that region: the Kome, Atane, Patoot and Atanekerdluk which he correlated respectively with the Urgonian, Cenomanian, Senonian, and old Miocene. The reviewer has regarded these floras as Barremian-Aptian, Turonian, Senonian, and upper Eocene or lower Oligocene respectively. All of these floras suffer from the uncertainties of mixed collections and over elaboration. There seems to be a relatively large number of species through the whole Cretaceous part of the section, which it seems emphasizes the failure to solve the local stratigraphy, although the presence of at least four different floras stands out clearly through this mist of uncertainty. Occurring as these plants do near the theoretical center of radiation of the flowering plants, this question of their true age is of the greatest importance. It is clearly worth the trouble and expense of field work in the region and its elucidation might well have added some luster to the almost total lack of scientific results of Peary's many expeditions.

E. W. B.

4. *Illinois State Geological Survey*, Frank W. DeWolf, Chief.—The following Bulletins have recently been issued: Number 34 on the Artesian Waters of Northeastern Illinois, by Carl B. Anderson. This is a volume of 326 pages with 4 plates and 3 diagrams in addition to a number of tables.

Number 36 (pp. 188 with 9 plates) is the Year Book for 1916 and contains the administrative report for the year ending June 30, 1917, by the Chief Geologist; also papers on the mineral resources of the State by N. O. Barrett; the clay deposits near Mountain Glen, Union Co., by Stuart St. Clair, and on the structure of the La Salle anticline by Gilbert H. Cady.

5. *Bulletins of the Buffalo Society of Natural Sciences.*—Volume XII, recently received, is devoted to a Catalogue of the Fossil Fishes in the museum of the Buffalo Society, by L. Hussakof and W. L. Bryant. The volume includes about 200 pages and 70 excellent plates, with numerous text figures. The collection is chiefly from the Devonian of western New York, and is

the largest that has ever been brought together from this source. A species of peculiar interest is named *Ptyctodus howlandi* in recognition of help and encouragement given, during the preparation of this important work, by Mr. Henry R. Howland of the Buffalo Museum.

Number I of Volume XIII (pp. 23 with 18 plates), is on the "Structure of Eusthenopteron"; by W. L. BRYANT.

6. *Guide to the Mineral Collections in the Illinois State Museum;* by A. R. CROOK. Pp. 294, with 31 plates and 236 text figures.—This is an interesting account of the Collections in the State Museum, numbering nearly 1300 specimens. Numerous illustrations are given, those in half-tone and in color being particularly noteworthy. The volume will be useful not only to those visiting the Museum, but also because of the fullness of its general descriptions to students of minerology.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Report of the Secretary of the Smithsonian Institution,* CHARLES D. WALCOTT, *for the year ending June 30, 1920.*—The Secretary states that the total funds of the Institution now amount to $1,083,000 and that the income available for the year was $174,000. Notwithstanding the special funds that have been added since the original gift from James Smithson in 1826, the income at present is quite too small to permit of the work being carried on as liberally as formerly, because of the greatly increased costs. However, the researches and explorations for the year have been very varied in subject and locality, not the least important being the work of the Secretary himself in the Canadian Rocky Mountains. It is interesting to note that the National Gallery of Arts is in future to be a separate unit under the Institution with Mr. W. H. Holmes as Director. The building, provided by the $1,000,000 given by Mr. Charles L. Freer of Detroit, is now nearly completed and practically ready for the installation of the collections. It is much to be regretted that Mr. Freer did not live to see his generous gift to the Nation put in permanent form. The International Exchange Service has increased largely, the number of packages handled during the year being nearly 370,000, weighing about 500,000 pounds. Although several countries are not included in the exchange list, the total number exceeds that of 1914 by over 27,000. The National Museum has acquired about 217,000 specimens, nearly half of these being in zoology. The Museum is now in charge of Mr. W. deC. Ravenel. Mr. Abbot, director of the Astrophysical Observatory, notes the practical completion of volume IV of the Annals. He also mentions the fact that the results for the solar variation for 1917 and 1918 obtained at Mt. Wilson and at Calama, Chile, 4,000 miles apart, agreed very closely. Through

the generosity of Mr. John A. Roebling, funds have been provided for the removal of the Chile Station to a mountain above its former location, thus giving a clear atmosphere, and, in addition, for a building on the Harqua Hala Mts. in Arizona.

Separate volumes, received recently, are the following:

Annual Report of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1918. Pp. 612, with 54 plates. The report of the Secretary, herein contained, has been already noticed.

Report on the Progress and Condition of the United States National Museum for the year ending June 30, 1919. Pp. 211, with 7 plates.

Several Bulletins of the Bureau of American Ethnology.

2. *Publications of the Allegheny Observatory of the University of Pittsburgh;* FRANK SCHLESINGER, director.—Publications recently received are as follows: Nos. 2-5 of volume **4** (1919) containing photographic determinations of the parallaxes of 135 stars with the Thaw refractor (185 stars for the entire volume). Also Nos. 1-5 of volume **5** on the same subject. Nos. 1-3 of volume **6** are on the following subjects: the irregularities in refraction (1); the effect of atmospheric dispersion on photographs taken with the Thaw telescope (2); solar and terrestrial absorption in the sun's spectrum from 6500 A to 9000 A (3).

OBITUARY.

DR. MAX MARGULES, formerly of the Austrian Meteorological Service, died on October 4 at the age of sixty-four years.

DR. KARL HERMANN STRUVE, in 1895 made professor of astronomy at Königsberg and later director of the Berlin-Babelsberg observatory, died on August 12 at the age of sixty-six years.

PROFESSOR YVES DELAGE, the eminent French zoologist, died on October 8 at the age of sixty-six years.

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

ART. VII.—*The Cretaceous Armored Dinosaur, Nodosaurus textilis Marsh*; by RICHARD SWANN LULL. With Plates I to IV.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

TABLE OF CONTENTS.

INTRODUCTION.

The "paleontologic revival" at Yale has as its first fruits the naming and description of new species out of old specimens in the Marsh Collection, some of which have awaited recognition for nearly half a century since they were exhumed. Incidentally there remains the other task of redescribing, in the light of further preparation and of greater opportunity for comparative study, such type material as had already had the scientific recognition of the master. Of such is the type of *Nodosaurus*, the importance of which is manifest when it is realized that it is not only a generic and specific type, but that of

the family of American plated dinosaurs, and was, moreover, essentially the first of these remarkable reptiles to be described in American literature of science. The preparation of the skeleton has been an arduous task, as it was sent in from the field in the form of shattered, bone-containing fragments of one or more great concretions. The only possible mode of procedure was to fit together these fragments and then, after pouring plaster into every bone impression in the rock where the osseous tissue had been eroded away, to hew the matrix from both the contained bone and the plaster continuation thereof. In this way, through weeks of patient toil, the creature has been revealed, and while by no means complete, will enhance very materially our present knowledge of these forms. *Stegosaurus,* although difficult to understand, is of course well known, owing to the researches of Marsh, Gilmore, and the writer, but it represents an aberrant side branch of the Stegosauria, and is early extinct (Morrison time), while *Nodosaurus* and its allies are in many respects more conservative and trace their lineage from the Lower Jurassic *Scelidosaurus* to *Ankylosaurus* of the Lance—almost the entire length of recorded predentate dinosaurian history.

Aiding in the work of preparation were F. W. Darby, a preparator of high skill and long service, Edward L. Troxell, associate on the research staff of the Peabody Museum, and others. I am also indebted to W. D. Matthew and Barnum Brown of the American Museum of Natural History for photographs and the privilege of studying the *Ankylosaurus* specimens collected by the latter; to Charles W. Gilmore of the United States National Museum for photographs and criticism; and to our lamented colleague, S. W. Williston, for the loan of the type specimen of *Stegopelta.* Mr. Kirkham of Yale aided in certain interpretations for which my knowledge was insufficient, while Professor Schuchert and Miss LeVene have as usual given their very real aid to the undertaking.

History of discovery.—When the veteran collector, William H. Reed, was working for Professor Marsh in 1881, searching for mammals and reptiles in the Morrison strata on the western slope of Como Bluff, Wyoming, he happened to discover the dinosaur which Marsh later described as *Nodosaurus textilis.* The specimen was found about 1½ miles east and south of the famous

Quarry 13 which was so highly productive of dinosaurian life (Gilmore 1914, pp. 2-24), and as it lay on the easterly slope of the Como anticline was therefore considerably above the Morrison stratigraphically. The label bears the statement "400 feet above the Dacota sandstone" in Professor Marsh's handwriting, while Reed's letter of July 17, 1881, says: "I found a saurian today in the Cretaceous between the Dacota rocks and the shale above them." This would bring it within the limit of the Benton sands and therefore in marine deposits, a not infrequent occurrence with the plated dinosaurs. The specimen lay in one or more concretions of dense bluish limestone which is extremely difficult to distinguish in some instances from the bone itself. The material was collected in fragments and its reconstruction has been a three-dimensional puzzle of great difficulty, especially as all of the pieces are evidently not preserved. Reed himself says in a letter dated July 12, 1882: "It is not very good and all in concretions so I could make no diagram of it."

Extent of Material.—The material as now prepared (1920) consists, first, of the pelvis, including the armored-over sacrum with the well preserved ilia attached. What appear to be the spinal ends of the scapulæ are also present, together with a detached mass containing portions of at least three imperfect vertebræ with their attached ribs and overlying armor. Yet another large piece contains a number of ribs with the highly nodular overlying armor. There is, however, no present connection between this and the other masses. Thirteen caudal vertebræ are also present. Of the appendicular skeleton, one approximately complete left femur is preserved, and parts of the other, the left tibia, and part of the fibula, a considerable portion of the right tibia, together with an almost complete left hind foot. Of the fore limbs, fragments of the humeri are present, together with the incomplete left radius and ulna, and portions of the fore foot. There are also a number of detached dermal elements.

The specimen bears the catalogue number 1815, 1815a, and 1815b Y. P. M., but there is no reason to suppose it to be other than one individual, and the number 1815 only will be used hereafter.

Original description.—Marsh (1889, p. 175) thus describes the animal:

"Another new member of the Stegosauria, from a lower horizon [than the Denver beds] in the Cretaceous, was discovered several years since, in Wyoming, and is now in the Yale Museum. The skull is not known, but various portions of the skeleton were secured. One characteristic feature in this genus is the dermal armor, which appears to have been more complete than in any of the American forms hitherto found. This armor covered the sides closely, and was supported by the ribs, which were especially strengthened to maintain it. In the present specimen, portions of it were found in position. It was regularly arranged in a series of rounded knobs in rows, and these protuberances have suggested the generic name.

"Near the head, the dermal ossifications were quite small, and those preserved are quadrangular in form, and arranged in rows. The external surface is peculiarly marked by a texture that appears interwoven, like a coarse cloth. This has suggested the specific name, and is well shown in the cut below [our Fig. 1].

"The fore limbs are especially massive and powerful, and are much like those of the Jurassic *Stegosaurus*. There were five well-developed digits in the manus [see below], and their terminal phalanges are more narrow than usual in this group. The ribs are T-shaped in transverse section, and thus especially adapted to support the armor over them [see, however, below]. The caudal vertebræ are more elongate than those of *Stegosaurus*, and the middle caudals have a median groove on the lower surface of the centrum.

"The animal when alive was about 30 feet in length. The known remains are from the middle Cretaceous of Wyoming."

This description was repeated almost verbatim in *Dinosaurs of North America*, 1896, p. 225, pl. 75, fig. 5, as Professor Marsh did not extend his study of the form. He prefixed the family designation Nodosauridæ at the beginning of this reprinted description, but without definition. In 1895 (p. 497), however, he thus defines it:

"Family Nodosauridæ. Heavy dermal armor. Bones solid. Fore limbs large; feet ungulate.

"Genus *Nodosaurus*. Cretaceous America."

This is also repeated verbatim in *Dinosaurs of North America*, p. 243.

MORPHOLOGY.

ENDOSKELETON.

Pre-sacral vertebræ and ribs.

(Pl. I, figs. 1-3; text fig. 2.)

One mass of matrix contains two nearly complete and apparently ankylosed vertebræ, with the attached ribs

of the left side and portions of the vertebræ preceding and following. They seem to pertain to, or to be somewhat posterior to, the mid-dorsal region. The mass also contains the antero-posterior calcified tendons lying on either side of the spinous process, and the overlying armor of the left side. The vertebræ themselves resemble those of *Stegosaurus* somewhat, but differ in that they do not show the extreme exaggeration of the elevation of the neural arch. They are in this respect more nearly of the proportions of *Polacanthus* and *Struthiosaurus,* in that the diapophyses originate slightly below the zygapophyses, although distally they rise above them. In so far as the centra are preserved, either in bone or by matrix impression, they are quite stegosaur-like. Laterally the centra show a distinct concavity as in *Stegosaurus,* but there is nothing comparable to a pleurocœle. The neural arch is robust, as are the

FIG. 1.—Dermal [subdermal] ossicles of *Nodosaurus textilis.* After Marsh. Natural size.

prezygapophyses, to which a portion of the postzygapophyses of the preceding vertebra, together with the spinous process, are so firmly united, in part by matrix, that the line of demarcation is nearly invisible. The diapophyses are curved on their external margin and are firmly ankylosed with the superior surface of the capitulum of the rib, as in *Ankylosaurus;* the two elements are clearly separated, however, by a deep groove. So far as one can see, the low tuberculum of the rib seems to be free from the diapophysis, but the space between is filled with an apparent matrix which is with great difficulty, and not always with certainty, distinguishable from bone. The neural canal is oval in section, with the apex uppermost, and is of considerable size.

The ankylosed left rib abuts against the neural arch, the facet being elliptical and elongated vertically. The rib has a sigmoid curve, being ventrally convex to the level of the tuberculum and thence concave. Beyond the tuberculum it is distinctly T-shaped in cross-section,

giving thus a broad bearing surface for the armor, although, as has been shown (Gilmore, p. 64), this type of rib is not confined exclusively to the armored forms. The lateral expansion of the rib begins as a low ridge about midway between the capitulum and tuberculum. The prezygapophyses overhang the centrum forward to a marked degree. The spinous process is thin, but has a marked fore and aft extent, with a straight superior margin. This may be seen from above where the armor is broken away, and exhibits little if any lateral expansion, being simply a thin plate of bone, narrowing slightly toward its posterior end. The spinous process overhangs the postzygapophyses, so that while obscured by matrix, its outline must have approximated that shown in the figure (text fig. 2). The outline of the bone seems to have resembled quite closely that of *Ankylosaurus* as figured by Brown (1908, fig. 11); it is also suggestive of *Stegosaurus*, but without the exaggerated heightening of the neural arch of the latter. Calcified tendons are present, lying close to and on either side of the spinous process. Those present diverge somewhat posteriorly. They are heavy and quite rib-like in appearance, except for their orientation and lack of curvature.

Measurements of Pre-sacral Vertebræ.

	mm.
Length over all	130
Height over all, est.	220
Centrum, length	88
Neural canal, width	13.5+
Width across pedicels	56
Width across prezygapophyses	68
Width across diapophyses	152
Spinous process, length of summit	66
Calcified tendon, width	14
Calcified tendon, depth	15.8

Pelvis.

(Pls. II, III.)

Sacrum.—The sacrum of *Nodosaurus* consists of three sacral vertebræ in the primary sacrum, and, as preserved, of at least four coalesced presacrals (sacro-lumbars) and two sacro-caudals, making a total of nine vertebræ in the entire syn-sacrum complex. The centra are so firmly

coössified that the line of demarcation between the successive vertebræ is practically obliterated; there is generally not even the usual dilatation at the articular ends of the centra to betray their limitations. Ventrally they are characterized by a median longitudinal groove, which is continued throughout the entire known series of caudal vertebræ as well. The anterior centra (sacrolumbars) are relatively long and slender, broadening posteriorly. The three primary sacrals bear heavy sacral ribs, the rounded lower margins of which are at the same level as that of the centra from which they arise. The expanded ends of the sacral ribs abut against

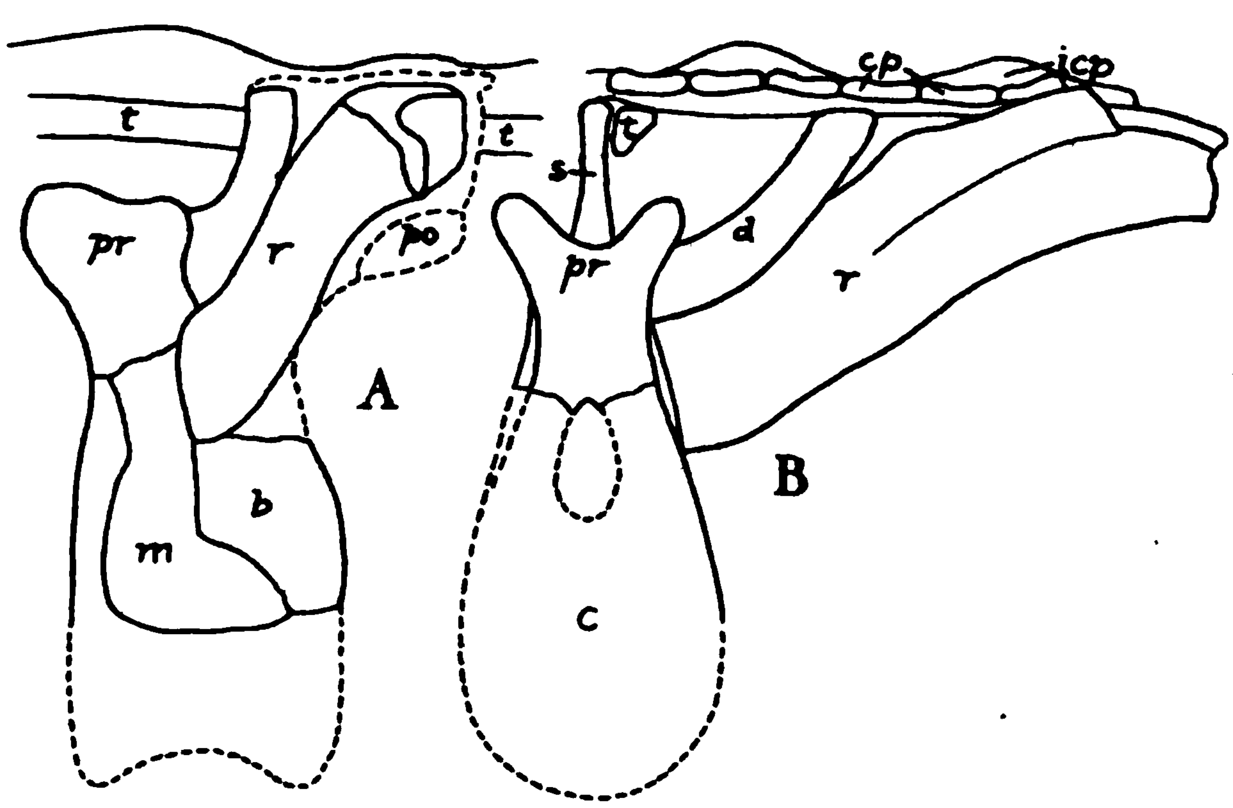

FIG. 2.—Dorsal vertebra of *Nodosaurus textilis*. A, left lateral, B, anterior aspect. One-fifth natural size. *b*, actual bone of centrum; *c*, centrum; *cp*, costal (armor) plate; *d*, diapophysis; *icp*, intercostal plate (seen beyond the costals); *m*, matrix impression of centrum; *po*, postzygapophysis; *pr*, prezygapophysis; *r*, rib; *s*, spinous process; *t*, longitudinal tendon.

the inner wall of the acetabulum, and the first two are more massive than the third. Dorsally these ribs are continuous with the diapophysial lamina, of which the horizontal upper plate passes into the surface of the ilium as seen from above (pl. II). The ribs borne on the four presacral elements are comparable except for their much greater slenderness. There is, as with the true sacrals, an expanded horizontal diapophysial lamina, especially near the vertebra and beneath the overlying armor. This arises, as does the rib, from the neural arch. Beneath this lamina, and united with it, without line of demarcation, lies the slender rib, the expanded horizontal portion extending at first entirely

behind the rib, so that the section of the bone at this point is roughly L-shaped. Further out, the rib becomes T-shaped in section, as its upper surface extends in front as well as behind. In the last pair of these ribs the vertical portion becomes practically obsolete at mid-length, and the bone becomes a thin blade-like expansion which merges into the thin inner margin of the ilium just in front of the acetabulum. This rib is clearly visible in plate II, and resembles the diapophyses of the three following sacral vertebræ very closely when viewed from above. The three anterior pairs of ribs were not visible from above, except for a fragmentary impression of one (pl. II), as they had been broken away beyond the

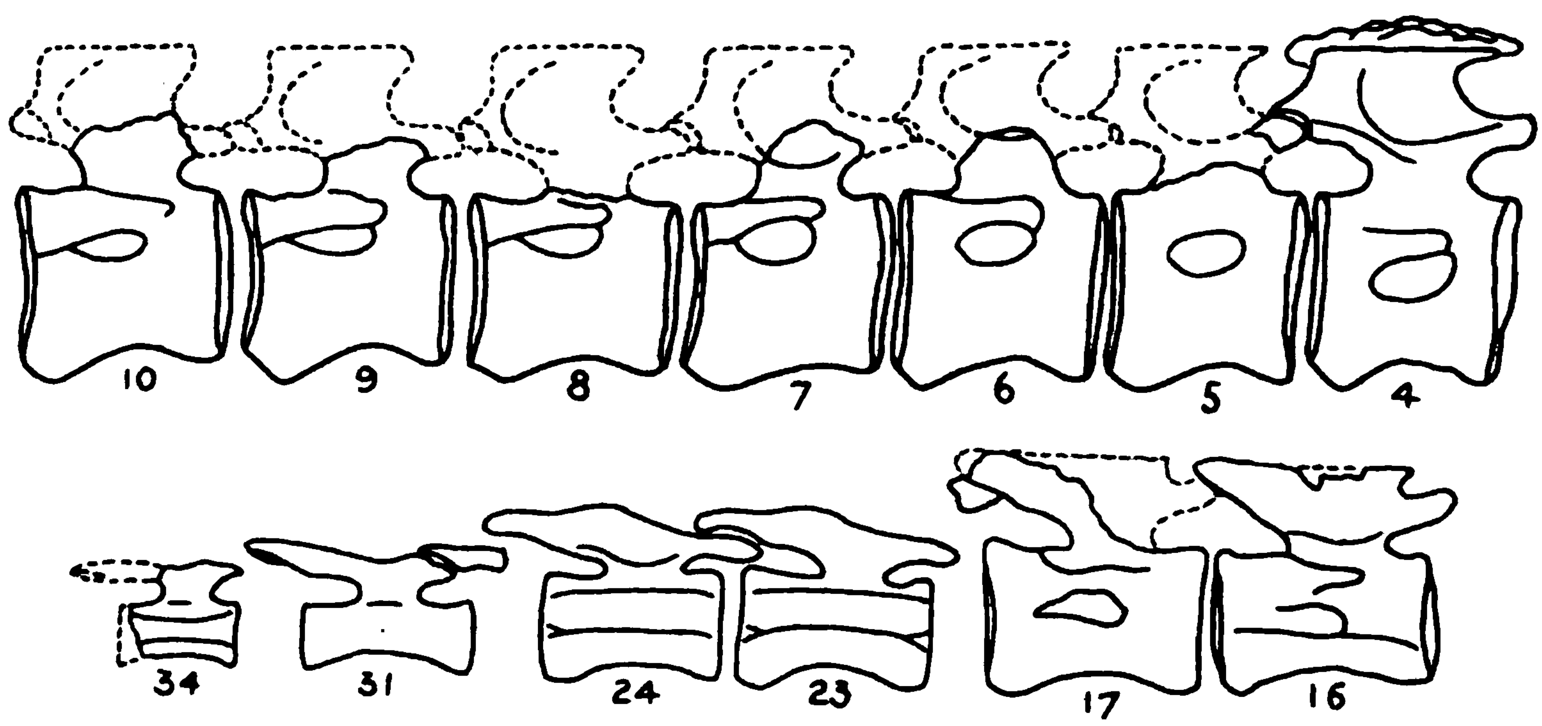

FIG. 3.—Caudal vertebræ of *Nodosaurus textilis*. Right lateral aspect. One-fifth natural size. Nos. 9 and 10, 16 and 17, 23 and 24, in contact in matrix.

preserved limitations of the sacral armor. It was only upon preparing the ventral side that they became evident (pl. III). The spinous processes of the entire syn-sacrum are coalesced into a continuous vertical plate of bone, the summit of which is visible at intervals in plate II, *s*, where the armor is lacking.

In the sacro-caudals, the first pair of ribs are typically T-shaped in section and extend, as do the second pair, outward and somewhat backward. The first pair evidently abutted against the posterior portion of the ilium, as a slight depression exists in about the right place. The restoration of the rib has been made accordingly. The presacral ribs probably extended to the ilium, as in *Polacanthus* and in the pelvis of *Ankylosaurus* on exhibition in the American Museum of Natural History, and

they have been thus restored (pl. III). The neural canal shows a sacral dilatation reaching an apparent maximum at the beginning of the primary sacrum, but it has by no means the exaggerated development shown in *Stegosaurus*.

Ilia.—Both ilia are imperfect, but in a measure supplement each other, so that except for the outline of the anterior portion, especially its forward limitation and its inner margin, the shape was probably as shown in plates II and III. The ilia lie largely in the horizontal plane except anteriorly and toward their outer margin, the iliac crest, where they curve downward. Dorsally their inner margin is continuous with the sacral diapophyses, which become more broadly wedge-shaped posteriorly and have their apex directly inward. The posterior extremity of the ilium is thickened, convex below, with a corresponding although much less pronounced concavity above. The remainder of the upper surface is relatively smooth, first concave and then convex from the rear forward. There are, however, well defined blood-vessel impressions indicating a close-fitting corneous investment, but no trace of overlying armor comparable to that over the sacrum. The iliac crest or margin is somewhat undulating and in places is thickened and rugose for muscle or tendinous attachment.

Ventrally, the ilia show three rounded ridges diverging from the acetabulum, flanked by four concavities of varying extent, of which the greatest lies beneath the whole anterior portion of the ilium. Behind this lies the lateral depression just without and almost confluent with the acetabulum. This receives the great trochanter of the femur. The acetabulum is large, almost perfectly hemispherical, and was bounded in front by a well developed pubic peduncle, the entire height of which is not preserved. The ischiatic peduncle was much lower and less well defined, but it also is ill preserved; it had, however, a rugose surface (pl. III, *i*). The inner margin of the acetabulum was well developed and buttressed by the three sacral ribs.

Sacral armor (see also page 120.)—The dermal armor over the pelvis, unlike that of either *Polacanthus* or *Stegopelta,* seems to have been confined to the sacral region only, although it probably in part overlay the inner margins of the ilia, and with them formed what Wieland has called the lumbar-hip carapace. In both *Polacanthus*

and *Stegopelta* the armor was continuous over and closely united with the ilia as well. The limitations of the elements which formed the sacral armor in *Nodosaurus* are very indistinct, but in so far as they can be identified are hexagonal. One near the anterior end of the pelvis, clearly shown in the photograph (pl. II), and susceptible of measurements, is 13.5 mm. in its greatest (transverse) diameter by about 75 mm. antero-posteriorly. This plate has a depressed superior surface, whereas that which adjoins its forward outer margin shows a distinct but low nodule (see below).

Measurements of Pelvis.

	mm.
Dorsal aspect:	
Length of sacral armor preserved	820
Breadth of sacral armor preserved	325
Breadth of sacral armor, est.	487
Breadth of pelvis	1273
Length of restored right ilium:	
Between perpendiculars	930
Over curve	1100
Width of right ilium to notch between diap. I and II	337
Length over diapophyses	320
Breadth of spinous processes	20
Ventral aspect:	
Length of nine coalesced centra as preserved	730
Centrum II, width, anterior end	70
Centrum II, width, center	57.5
Ant.-post. diameter, diapophysis	43
Height of vertebra II, about	120
Height of ilium at pubic peduncle, est.	185
Acetabulum, length	14
Acetabulum, breadth	17

Comparison with other genera.—A very close resemblance exists between this pelvis and that of *Polacanthus* (cf. Hulke 1887, pl. 9), which is of course especially in evidence when the latter is viewed from below. *Polacanthus* shows the same characters in the centra,—slender anteriorly with very vague demarcation between the successive vertebræ. Hulke indicates five sacrals, the anterior one bearing light but transversely expanded ribs, as in that which I have called the last sacro-lumbar. He shows in sacrals 2 to 4 bones comparable in their development to the true sacrals of *Nodosaurus*. His

sacral 5 corresponds to my first sacro-caudal and shows a rib which is nearly as robust as that of sacral 4 and which runs nearly parallel with it and is coalesced with the posterior portion of the ilium. Another vertebral centrum which is partially detached Hulke calls a caudal; in *Nodosaurus* the equivalent of this is coössified with the rest and forms the second sacro-caudal. In front of sacral 1 of Hulke there are five pairs of slender, rather irregular ribs apparently partially attached to the overlying armor. In a later figure by Seeley (1892, fig. 1) these are shown as lying *above* the ilia but beneath the armor. There is no evidence that this is true in *Nodosaurus*, for,

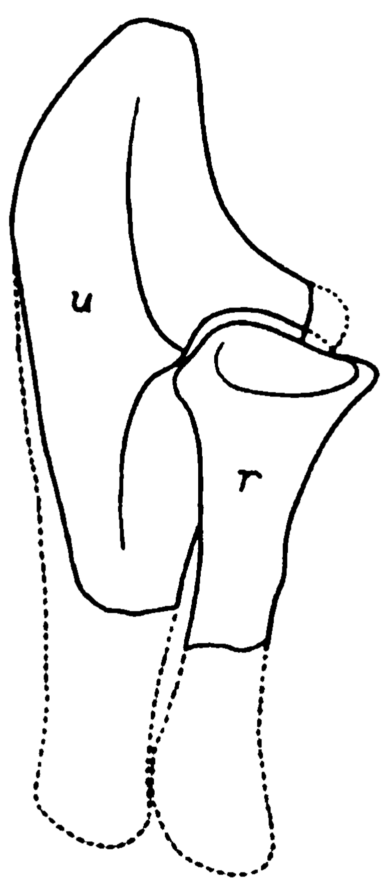

FIG. 4.—Right radius and ulna of *Nodosaurus textilis*. Inner oblique aspect. *r*, radius; *u*, ulna. One-eighth natural size.

as Lydekker (1892, p. 85) remarked, the position of the ilium of *Polacanthus* internal to the ribs is a character found elsewhere only in adult tortoises, in which it is probably due to the impact of the shield on the ribs, thus rendering it impossible for another bone to grow between them, a condition which would not occur in *Nodosaurus* because of the lateral limitations of the sacral shield.

The pelvis of *Nodosaurus* differs from those of both *Polacanthus* and *Stegopelta* in the absence of dermal armor from above the ilia. In both genera mentioned, the armor is firmly coalesced with the ilia, although in the character of the sacral armor *Stegopelta* is nearer its contemporary *Nodosaurus* than is *Polacanthus*.

Caudal Vertebræ

(Pl. I. fig. 5; text fig. 3.)

Thirteen caudal vertebræ are present, together with impressions in the matrix and fragments of at least four more. The vertebræ seem to be fairly representative of the entire series, as there are seven apparently proximal ones, two from near the middle of the tail, two from the posterior two thirds, and two from near the distal end.

Judging from the character of the sacrum, with its

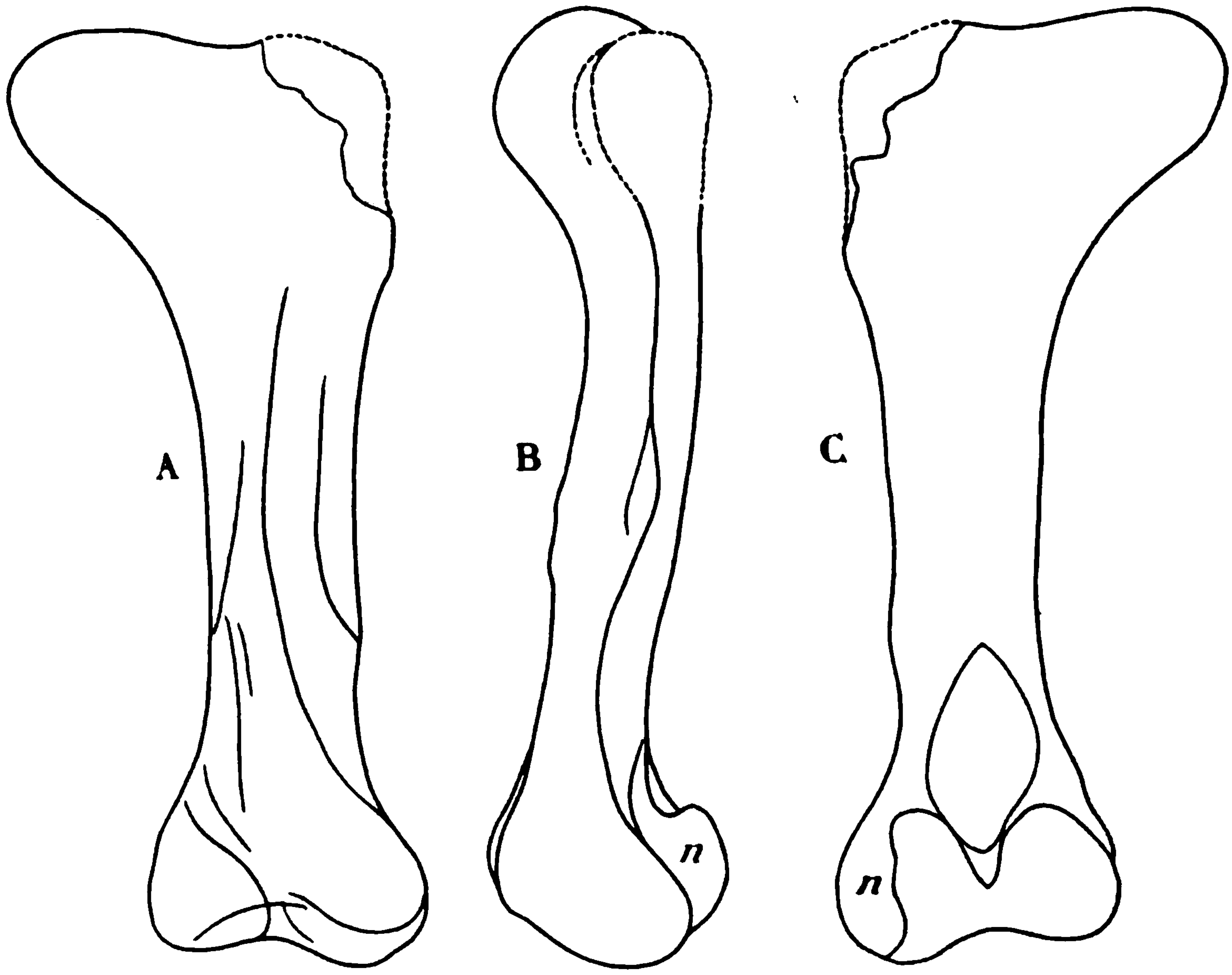

FIG. 5.—Left femur of *Nodosaurus textilis*. A, anterior, B, external, C, posterior aspect. *n*, notch. One-eighth natural size.

small centra and low spines, there are no caudals which correspond to the short, high-spined, large-centrum, anterior caudals of *Stegosaurus* in form. The correspondence is, on the other hand, more with the anterior caudals of *Scelidosaurus*. The numbering of the caudals in the following description is arbitrary and merely approximate.

Caudal 4 (pl. I, fig. 5; text fig. 3).—This bone is well preserved, having the entire neural arch and spine, overlain on the left with dermal bones. While both diapophyses are absent, the impression of that of the left

side is still to be seen in the matrix, and from it that of the right has been restored. The centrum is roughly cylindrical and the length is somewhat less than its greatest diameter. Ventrally it is characterized by a shallow longitudinal groove which Marsh mentions in his original description, and there is evidence of at least one chevron facet at its posterior end. Laterally there is no trace of pleurocœle, and the diapophysis arises from a little above the middle of the bone. The diapophysis is light, and curves somewhat toward the rear. Below the diapophysis, the surface of the centrum is somewhat concave, with evidence of a faintly impressed vertical groove. The anterior face is practically plane, the posterior slightly concave.

The pedicels are of considerable antero-posterior length, which somewhat exceeds half the length of the centrum. The pedicels are simple, being unsupported by buttresses or laminæ. The spinous process is thin but expanded fore and aft, so that its total length is nearly as great as is that of the entire centrum. The summit merges into a layer of irregular dermal bones which extend in a horizontal manner from the left side; on the right they are not preserved. The zygapophyses are simple, those in front looking inward and upward, while those in the rear look downward and outward. A slight fore-and-aft lamina—horizontal lamina—connects the zygapophyses on either side with each other; above these the face of the spinous process is for the most part concave. The neural canal is oval in section, with the apex uppermost, and is of considerable size, as the measurements show. The ventral median groove and the character of the low spinous process are the most distinctive features of this bone.

Caudals 9 and 10 (fig. 3).—These were in contact in the matrix and except for their processes are very well preserved. No. 10 is a little the wider. The anterior face of the centrum shows a slight dorso-ventral convexity, and the posterior face is correspondingly but somewhat more markedly concave. Transversely, each face is flat. The ventral groove is apparently deeper than in caudal 4 and the posterior chevron facets are especially marked. The better preservation of the bone surface leads to the supposition that these and other distinctions from caudal 4 are more apparent than real. The diapophyses are not preserved, but their bases are

situated somewhat higher on the centrum than in No. 4 and apparently the processes themselves were lighter. The same shallow vertical groove is discernible on the centra, and the surface of the latter is slightly rugose toward the articular faces, especially ventrally. A slight fore-and-aft ridge runs from the hinder margin forward about two thirds the length of the bone above the diapophysis.

Caudals 16 and 17 (fig. 3).—These vertebræ were also in contact, and No. 16 particularly is very well preserved. It also has numerous small dermal ossicles associated with it, together with an oval armor plate (see below).

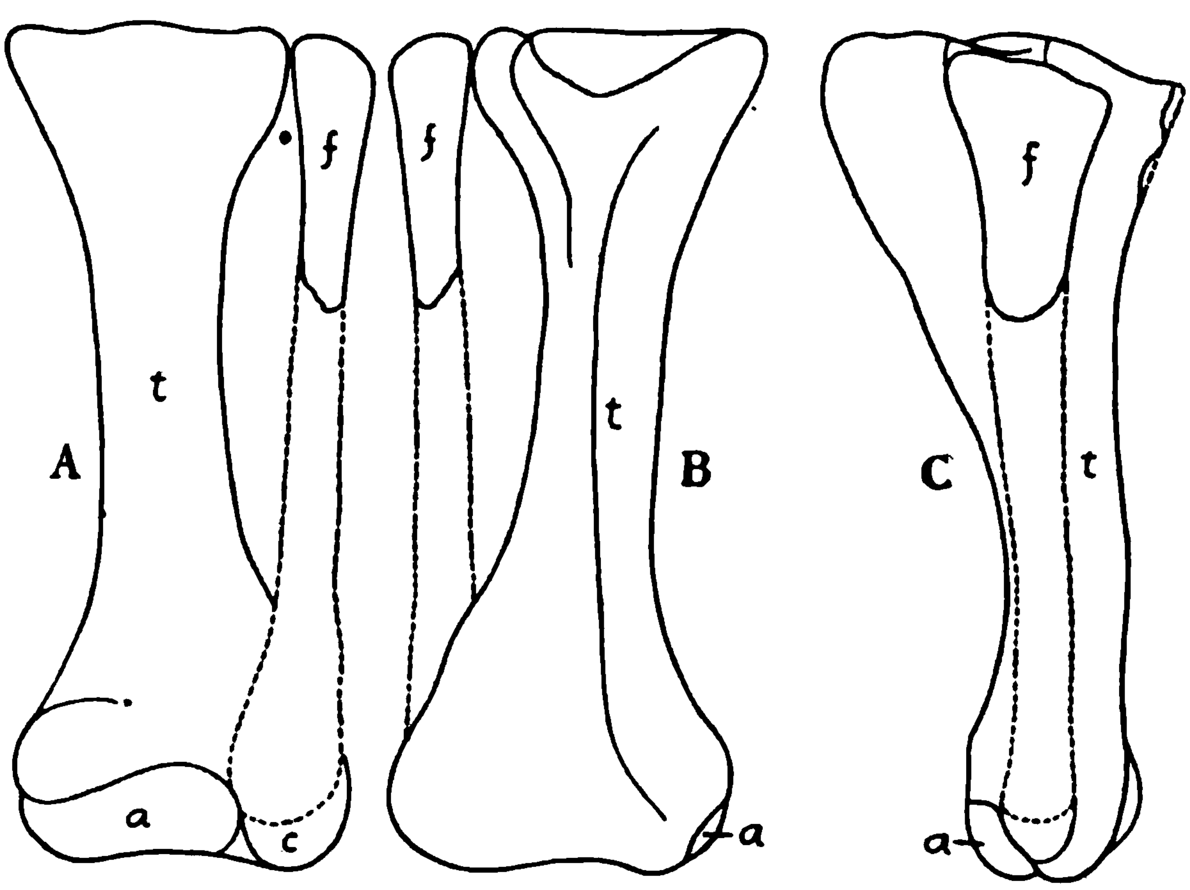

FIG. 6.—Left tibia and fibula of *Nodosaurus textilis*. A, anterior, B, posterior, C, external aspect. *a*, coalesced astragalus; *c*, calcaneum; *f*, fibula; *t*, tibia. One-eighth natural size.

Caudal 16 is relatively longer and slenderer of centrum than are caudals 4 to 10, implying a gap of perhaps five vertebræ between it and the tenth. The articular faces of the centrum are essentially plane and the centrum itself begins to exhibit the distinct longitudinal ridges seen in Nos. 23 and 24. Diapophyses are still present and arise about the middle of the bone. The spinous process is strong and prolonged fore and aft, the postzygapophyses merging into the posterior angle of the spine. Horizontal laminæ are faint, but distinct. Both zygapophyses overhang the centrum.

Caudals 23 and 24 (fig. 3).—These are again in contact, with an estimated omission of perhaps six vertebræ between them and No. 17. Here the diapophyses are

lacking, but longitudinal ridges give the centra almost a fluted appearance. The ventral grooves are especially marked. The neural arch and spinous process, proportionally to the centrum, are much as in Nos. 16 and 17. The superior margin of the spinous process is curved, in contrast to the straight margins which have characterized those before.

Caudal 31 (pl. IV, fig. 1; text fig. 3).—This bone is markedly different from its predecessors in the lack of fore-and-aft ridges on the centrum, and in the character of the zygapophyses. The prezygapophyses are short, not extending to the end of the centrum, while the postzygapophyses are very long, with an extremely long articular facet. There is no upward extension of the spinous process above the zygapophysial level, unless a small rounded eminence over the prezygapophyses represents it.

Caudal 34 (fig. 3).—This caudal is imperfect but is curiously abnormal in that the very narrow ventral groove lies well toward the left side of the rather broadened lower aspect of the bone. Otherwise the bone shows no marked distinctions from caudal 31, except that the centrum is not apparently prolonged in front of the pedicel to the extent that it is in the latter.

Measurements of Caudal Vertebræ.

	4 mm.	17 mm.	24 mm.	31 mm.
Length over all, over zygapophyses	86.5		69	87*
Height over all	114	77 +	53.5	43
Centrum, length	65.5	73.5	62.5	57
Centrum, ant. face, height	64	50 ±	35.5	24
Centrum, ant. face, width	68	55	40 ±	
Centrum, ant. face, circumference	210	165 ±		
Centrum, post. face, height	66	52.5	35.5	23
Centrum, post. face, width	69.4	54 ±	43.5	31
Centrum, post. face, circumference	215	190 ±	135 ±	
Neural canal, ant. end, height	23	13		5
Neural canal, ant. end, width	12.5	9.5		
Width across pedicels	30			
Width across prezygapophyses	39			
Width across postzygapophyses	39	13		
Spinous process, length, summit	64.5			
Index, centrum, length to height, ant. face	1.0234	1.47 ±	1.732	2.376

* Postzygapophysis prolonged.

Fore Limb.

Scapula (fig. 7).—Both scapulæ are represented by fragments which unfortunately do not supplement one another, as they all pertain to the extremity of the blade.

FIG. 7.—Restoration of *Nodosaurus*. Based upon Brown's restoration of *Ankylosaurus* for the ribs, and scapula. Fore limbs partly from *Stegosaurus stenops*. Skull a compromise between *Scelidosaurus* Stippled bone actually present. The position of the presacrals is not assured, but they probably did not vary the dorsal series. The mass of armor probably came from further forward, but was presumably similar over the entire dorsal half of the torso.

One twenty-fourth natural size. Estimated length between perpendiculars, 14 feet; on curve, 17½ feet (Marsh estimate, 30 feet); height to mid-back, 5 feet.

The largest fragment belongs to the right scapula, and is massive, with a curved extremity. The lateral margins are roughly parallel and the bone is not only curved in two dimensions but twisted as well, as though it fitted closely over the curved ribs. It resembles, in so far as a comparison can be made, that of *Ankylosaurus* (Brown, 1908, fig. 15), but has about three fourths the dimensions of the latter.

Measurements of Scapula.

	mm.
Width at extremity	172.5
Thickness	33
Max. thickness of fragment	49.5

Humerus.—Several fragments which are believed to pertain to the humerus are present, but are inconclusive and not worthy of description. They do, however, give a check on relative proportions (see restoration, fig. 7).

Radius and ulna (pl. IV, figs. 2, 3; text fig. 4).—The proximal ends of the right radius and ulna, and a portion of the left ulna, are present and are typically stegosaurian or ceratopsian and totally unlike those of any other dinosaurian group. The olecranon process is very massive and extends considerably beyond the humeral articulation. The humeral facet, however, covers about half of its anterior face. The radial facet is a clearly defined depression and gives the bone a triangular cross-section at that point, with two hollow faces. The articular face, as with the femur and tibia, had a smoother, more finished appearance than in the *Stegosaurus* specimens I have seen. Proximally and externally the grain of the bone is coarse.

The radius shows an ovate cross-section in the shaft, but is somewhat more irregular in outline at the expanded proximal end. The proximal face bears a circular saucer-shaped depression, whereas in *Stegosaurus* such a depression is barely discernible. The difference may be due to the relatively thick articular cartilage in the latter as compared with that of *Nodosaurus*, as indicated by the rugose character of the articular ends in *Stegosaurus*. Aside from this and certain proportional distinctions, the resemblance of *Nodosaurus* to *Stegosaurus* in these elements is quite marked. The elbow must have been very readily flexed and carried in a partially bent

position. The character of the proximal radial facet would indicate a rotatory movement as well, but whether the distal end of the ulna would bear this out is of course impossible to ascertain from the present material. The insertion of the biceps muscle on the radius is clearly indicated.

Manus.—Marsh speaks of the manus in some detail; I find, however, but few bones which through a process of elimination may have pertained to the manus, as the remainder seem to be those of the nearly complete pes. There are two complete metacarpals, apparently the second and fourth, and fragments of one, probably the third, as it was in contact with the second. Some of the scattered phalangeal elements may also be of the hand but they are difficult to place. If these bones really pertain to the hand, they are exceptionally long, as the entire ones, though more slender, are fully equal in this dimension to their apparent equivalents in the pes, differing in this regard from *Stegosaurus*, but if Baron Nopcsa's restoration (1905, pl. 12) be correct, resembling the proportions of the Wealden *Polacanthus,* which in many respects is similar to the form under discussion (see under generic comparisons, *infra*).

Metacarpal III has a subtriangular proximal face with a rounded rugose area on the outer side. Distally the articular end is semi-cylindrical, dilating somewhat externally. The mid-shaft section is subtriangular, with rounded faces. The shaft bears two low tuberosities on the posterior oblique face. Metacarpal IV is somewhat more slender and has a short proximal phalanx in articulation therewith. An ungual is also present, and while its form may be somewhat attenuated, due to erosion of its lateral margins, it seems to have been much more claw-like than were those of the pes.

Measurements of Metacarpals.

	mm.
Metacarpal II	
Length over all	125.6
Max. diameter, proximal end	57.6
Max. diameter, distal end	65
Max. diameter, mid-shaft	38.3
Length of entire digit	ca. 245
Metacarpal IV	
Length over all	123

Hind Limb.

The limb-bones of the type specimen of *Nodosaurus* differ decidedly from those of *Stegosaurus* or *Hoplitosaurus* in the smoothly rounded character of the articular ends, which in the latter genera are rugose, indicating articular cartilages of considerable thickness. The cartilage in *Nodosaurus* was doubtless relatively considerably reduced. On the other hand, the surface grain is more distinct in *Nodosaurus,* giving a fibrous character to the bone which seems to be unique. These features, together with the extreme ankylosis of tibia and astragalus (see below), are interpreted as indications of the advanced age of the individual, in which the articular cartilages would become more perfectly ossified and the bony tissue of the limb bones might in a sense invade the tendinous muscular attachments as well. (See pl. IV, figs. 4, 5.)

Femur (pl. IV, fig. 4; text fig. 5).—The left femur is complete as to length and well preserved, although portions are missing, notably in the region of the several trochanters, the extent of which can not, therefore, be ascertained. The bone is less straight than in *Stegosaurus,* and in its degree of curvature resembles more nearly that of *Hoplitosaurus* (Gilmore 1914, fig. 69), especially when comparison is made with the actual bone (U. S. N. M. No. 4752). In Mr. Gilmore's figure (fig. 69, 3) the lower curve of the shaft has been exaggerated to correct for crushing, giving a decided S-shaped outline to the bone when viewed from the side. Thus the knee of *Nodosaurus* must have been habitually partially flexed, giving a very different appearance to the limb from that of the mounted *Stegosaurus ungulatus* at Yale (Lull 1910, pl. II and fig. 2). The surface of the shaft in the *Nodosaurus* femur also agrees with *Hoplitosaurus* rather than *Stegosaurus* in that the limitations of the muscle areas are clearly defined by well developed ridges, whereas in *Stegosaurus* the surface is relatively smooth. The great trochanter is missing, but the preserved outline of the summit of the bone seems to indicate that it was more prominent than in either *Hoplitosaurus* or *Stegosaurus,* as figure 5 shows.

While the fourth trochanter is missing from the bone, there is no reason to suppose that it was more than a mere roughened area for the insertion of the caudofemoral muscle. This is in keeping with the strictly quadrupedal gait of the animal. The anterior aspect

exhibits a number of the ridge-enclosed muscle areas mentioned above. One ridge arises from the region of the great trochanter and descends somewhat obliquely two thirds the length of the bone. It is separated externally by a wide, shallow, oblique groove from a second muscular area on the antero-external face of the bone. The internal condyle is the larger of the two when viewed from the rear. In front they are more nearly equal and the inner one is defined by a narrow curved groove which arises on the inner face of the femoral shaft and runs obliquely down between the condyles. Posteriorly the external condyle, as in *Hoplitosaurus,* while having a somewhat greater fore-and-aft diameter than the internal one, is nevertheless very much narrower, especially toward the distal end of the bone, thus forming a deep vertical notch between the external surface of the condyle and the remainder of the articular surface (see fig. 5 B and C, *n*). Above the condyles the shaft bears a rather deep ovoid depression, above which the surface of the bone exhibits an interwoven fibrous surface resembling the textile character of the dermal ossicles which suggested the specific name of the animal. A cross-section of the mid-shaft has a somewhat trihedral form, being flattened on the posterior aspect.

Tibia. (pl. IV, fig. 5; text fig. 6).—The left tibia is approximately entire, although the two halves were not together nor were there definite "contacts" between them. The bone may therefore have been somewhat longer originally, but could not have been shorter. The distal half of the right tibia is also present, together with a portion of the proximal articular extremity. There is a chance for error in the orientation of proximal and distal halves, but the surfaces curve into one another fairly, so that the error is probably not great. As restored, the long axes of the articular ends make a greater angle with each other than in *Stegosaurus,* and the curvature of the bone is somewhat greater. Proximally, the bone is expanded and narrows rather rapidly into the shaft, to expand again distally. The distal extremity is more flattened in one diameter (antero-posterior) than is the proximal, and the astragalus is so closely ankylosed with the bone as to be almost undiscernible, forming a smoothly rounded though somewhat pitted articular face (see above). In *Stegosaurus* the astragalus, while coalescing with the tibia with age, is

very distinct in all specimens known to me. The surface of the tibial shaft is less characteristic than that of the femur, and in this regard is more *Stegosaurus*-like. Whether the calcaneum was present or not I can not be sure, but a detached concavo-convex bone may represent it.

Fibula (pl. IV, fig. 5; text fig. 6).—The proximal end of the fibula is present, as indicated in the figures, but while held in position by the matrix, it had evidently shifted somewhat downward. The impression of the distal end is also preserved in the matrix, but is quite evidently out of position, having shifted inward upon the face of the tibia away from the regular fibula facet, which is a clearly defined flattened area. The fibula seems to have been relatively more robust than in *Stegosaurus*, especially in its antero-posteriorly expanded proximal end.

Measurements of Limb Bones.

	1 mm.	2 mm.	3 mm.	4 mm.	5 mm.	Ratios Cols. 1 and 5
Femur:						
Length	975	1080	1200	495	593	1.644
Max. breadth, prox. end	266	283	329	190	180	1.477
Max. breadth, dist. end	251	276	263	170	230*	1.091
Min. width, shaft	114	145	147	65	93	1.225
Average ratio						1.357
Tibia:						
Length	630	643	696		454	1.385
Max. width, prox. end	247	265	275		182	1.356
Max. width, dist. end	238		245		182	1.307
Min. diam., shaft	79	85	98		61	1.295
Average ratio						1.333
Ratio, fem.: tib., length	1.548	1.679	1.724		1.306	1.184

1 = *Stegosaurus stenops*, Y. P. M. 1856. Femur and tibia may represent different individuals.
2 = *S. stenops*, U. S. N. M. 4934, right.
3 = *S. ungulatus*, U. S. N. M. 6646.
4 = *Hoplitosaurus marshi*, U. S. N. M. 4752.
5 = *Nodosaurus*, Y. P. M. 1815.
* Estimated.

Pes (fig. 7).—A partially complete left hind foot has been assembled from the material pertaining to this specimen and proves to be strikingly suggestive of that of *Monoclonius* (Brown 1917, pl. 12, E. G.). There are four well developed digits, digit I, while shorter, being fully as robust as the others. The proximal surface of metatarsal II is concave, that of the others convex.

Metatarsal II has also the greatest proximal area. Some question may exist as to the position of the phalanges, but some were in contact, and of these there can be no question. Digit I is correct throughout, of II the associated ungual is doubtful, of III there is little question, but IV is incomplete. The metatarsals are narrow in mid-length, with dilated extremities, and the unguals are broad and hoof-like. The articular ends of the bones are relatively smooth, as with the limb bones, but here the distinction from *Stegosaurus stenops* (Y. P. M. 1856) is less marked, as the proportion of articular cartilage must have been relatively small in either case.

Measurements of Pes.

	mm.
Metatarsal I, length	85
Entire first digit, length	210
Metatarsal II, length	125
Metatarsal II, max. diameter, proximal end	73
Metatarsal II, max. diameter, distal end	71
Metatarsal II, max. diameter, mid-shaft	42.5
Entire second digit, length	240
Metatarsal III, length, est.	130
Entire third digit, length	290
Metatarsal IV, length	124

Exoskeleton.

Armor.

General character.--Marsh's description of the armor of *Nodosaurus* defines two types of elements, the one regularly arranged in a series of rounded knobs in rows which suggested the generic name, the other consisting of dermal ossifications placed *near the head* (italics mine). These were described as quite small, quadrangular, arranged in rows, with their external surface peculiarly marked by a texture that appears interwoven, like a coarse cloth. This has suggested the specific name and is well shown in the only figure Marsh published to represent the animal (our fig. 1). His reference of these elements to a position near the head is not founded upon observed fact, as no trace of the head and neck of the animal is present, but was probably reasoned from analogy, as small rounded scutes have been found *in situ* near the head of *Stegosaurus*. As a matter of fact, the two sorts of dermal elements were contiguous, and in

certain portions of the body, as over the ribs, the one series in part overlay the other. What they really represent was suggested by Wieland (1911, 1912), although not for *Nodosaurus* specifically. They are ossifications of the two—the outer and the nether—dermogene layers, the larger nodular plates being derived from the outer and the lesser from the nether. Wiedersheim (1907, p. 25) states:

> "In the derm [of reptiles], a superficial and a deeper layer may be distinguished. The latter is composed mainly of strong bundles of connective tissue fibres which as a rule cross one another at right angles, as in fishes and amphibians."

This would account for the textile character of the smaller subdermal (nether-layer) ossicles which are merely ossifications or calcifications of this fibrillar connective tissue. Marsh's statement that the interwoven striæ are on the external surface is true, but they are just as visible on the internal surface and there is reason to believe that in the figured specimen the inner and not the outer aspect is exposed, as armor plates of the dermal (outer dermogene) layer lie contiguous to the surface which is embedded in the matrix. Another fragment shows the relative position of the two armor layers very clearly. The ossicles of the subdermal layer average some 16 mm. square, though varying in length. Their thickness averages about 3 mm. (see fig. 1).

Dorsal armor.—One mass of matrix contains a group of five or six ribs (pl. 1, fig. 3) overlain in part by the armor. The ribs themselves have shifted somewhat from their position during life, so that at least three of them converge distally (*r, r*). These three are mainly matrix impressions, with very little actual bone remaining, and here the armor is lacking. The other ribs are covered with the typical nodular armor of the outer dermal layer, and here again two sorts of scutes are discernible, for the larger nodular scutes are intercostal (*icp*) in position as preserved and are separated one row from another by a series of smaller rectangular scutes (*cp*), the surface of which is approximately plane except for the rugosity of the entire outer dermal series. The rows of smaller rectangular scutes are costal in that they approximately overlie the broadened outer surface of the ribs, although sometimes shifted slightly *post mortem*. The smaller scutes average 25×28 mm. in size. They are not everywhere distinct, but were probably pretty regularly dis-

tributed throughout this mid-torso region of the body. The nodular intercostals average about 80×55 mm. in size, the greatest diameter lying parallel with the ribs. The nodules are well rounded eminences, elliptical in section, and rising some $15\pm$ mm. above the general level of the scute. The nodular scutes thus form regular transverse rows across the creature's back. They seem to have formed longitudinal rows as well, as in the crocodiles, and at least nine such longitudinal rows existed on either side of the midline, probably more in this region of the body (see restoration, fig. 7). Toward the distal ends of the ribs, which are, however, not complete, the scutes of the subdermal layer become visible and one can view their passage dorsally beneath the dermal scutes (*sd*). The scutes give an impression of crowding in the longitudinal axis of the body, as though the force that tended to converge the ribs distally had also wrinkled the skin. It would seem, therefore, as though, as in the alligator, the nodular (or keeled) scutes are dorsal, the flanks and belly being protected by smaller elements. The homology is not, however, precise, for in the crocodile the subdermal armor is lacking and the lateral and ventral protective elements are entirely cutaneous. In *Nodosaurus* a cutaneous investiture was of course present, but seems to have been in a larger degree supported by osseous dermal and subdermal scutes.

In the group of vertebræ described above, the proximal ends of the ribs only are preserved. They bear comparable dermal scutes similarly arranged, with, however, no trace of the subdermal elements. Over the vertebræ themselves the nodular scutes are larger, somewhat hexagonal, although irregularly so, averaging 80×86 mm. in size, with the greatest diameter fore and aft. There is no median row, single as in the turtle, but two, one on either side of the spinous processes, form the neural series (pl. I, fig. 1, *np*).

Sacral armor.—On the sacrum the armor plates are very obscurely defined, but are in the main hexagonal, although very irregular in outline, the two neural rows being continuous with those just mentioned. Whether they were separated during life by the now visible summits of the spinous processes is not clear. The armor, as has been said, did not form a complete shield as in *Polacanthus,* but was confined to a longitudinal belt overlapping only the sacral diapophyses and not the ilia.

Deep blood-vessel impressions on the superior inner portion of each ilium, which appear somewhat abruptly along a definite line, seem to indicate that beyond that line the dermal armor ceased and the cutaneous investment was closely applied to the surface of the ilia themselves (see above, page 105, and pl. II). Thus the latter formed an endoskeletal continuation of the median dermal carapace. The actual dermal scutes are not preserved for the full width of their former extent (see pl. II). The nodular prominences over the sacrum are almost obsolete, increasing apparently in height forward toward the dorsal region and laterally in that region from the neural series outward. There is no preserved trace of subdermal ossicles in the pelvic region of *Nodosaurus.*

The evidence afforded by *Nodosaurus* emphasizes Wieland's statements concerning the dinosaur-turtle analogy. In the crocodile-like reptiles, the outer dermogene-producing layer only is present;[1] the turtles had originally both outer and nether dermogene layers. The latter early tended to strengthen and use the under layer only. The dinosaurs developed both body and cranial armature in both upper and nether dermogene layers. The latter, Wieland thinks, gave rise to the huge plate roofing the entire skull in *Ankylosaurus* and the hip armature of *Polacanthus.* However the greater portion of the *Polacanthus* carapace may have originated, the occasional keeled plates which arise above the level of the main structure seem to be homologous with the nodular scutes of *Nodosaurus* and thus to be, like those of the crocodiles, of outer dermal origin. Thus the dinosaurs, as Wieland says, instead of eventually confining extensive dermal development to but a single nether layer, covering the body region only as in the turtles, tended to develop both the nether and outer layers in body or skull, or both.

[1] Scutes from *Deinosuchus hatcheri,* a Judith River crocodile, described and figured by Holland (Ann. Carnegie Mus., 6, 291, 1909) "show on the under surface numerous fine straight lines decussating with each other at an angle of about 45°, indicating the structure of the dermal tissues in which they were embedded and to which they adhered." Sir Richard Owen (Rept. British Assoc., 1841, p. 71) calls attention to a similar feature in the scutes of *Goniopholis crassidens* Owen. The figure (fig. 10) published by Holland shows a very distinct layer, in part broken away from the overlying cancellous bone, which bears the intersecting lines. This would seem to indicate that the scute as a whole is of dual origin, derived in part from the outer dermal and in part from the subdermal layers.

Keeled plate.—One keeled plate free from its attachment is associated with the *Nodosaurus* specimen (pl. I, fig. 4). It is similar to those of *Ankylosaurus, Hoplitosaurus* (Gilmore 1914, fig. 70), and *Hierosaurus* (Wieland 1909, fig. 5), and measures 143 mm. long by 99 mm. wide and 27 mm. high. This plate was one of a pair from the left side of the body, and probably came from near the base of the tail. It is almost the counterpart in size and appearance of the *Hierosaurus* element shown by Wieland in his figure 5, except that in the *Nodosaurus* plate the keel is lower, due in part to its having been broken away.

Caudal plate.—Yet another plate of a similar character, except that it rises to a point at one end instead of bearing a keel, is associated in an inverted position with caudal 17 and must have formed one of a row which lay on either side of the mid-line along the dorsal surface of the tail. The under surface is concave, especially under the above-mentioned point. Above, it is pitted and also bears vascular grooves. Subdermal ossicles apparently underlay it, as they now lie between it and the spinous process of the caudal.

Measurements of Caudal Plate.

	mm.
Length	77
Width	59
Height	19.5

Spine-like plate.—This element, while incomplete, is very suggestive of the dermal plates of *Hoplitosaurus* as figured by Gilmore on his plate 30, and also that of *Hierosaurus* shown by Wieland on his figures 3 and 3a (1909). Similar plates are also associated with *Polacanthus* and gave the reptile its generic name. Nopcsa (1905, pl. 12) figures such elements along the presacral vertebræ, a row on either side. In *Nodosaurus*, this element is large, with a somewhat elliptical base and two sides concave in their vertical diameter and convex fore and aft. The basal portion is ill preserved, but was in part at any rate highly rugose. The lateral faces resemble the limb bones in their surface texture, but were impressed with shallow vascular grooves. The size is greater by far than that of the plate of *Hierosaurus* and its fore-and-aft diameter exceeds that of *Hoplitosaurus.*

Dimensions are minimum and were probably exceeded in the perfect bone.

Measurements of Spine-like Plate.

	mm.
Preserved length	240
Preserved width	110
Preserved height	135
Estimated height, ca.	250

Mr. Gilmore's statement that "these skin ossifications in *Hoplitosaurus* present far more variety of form than do those obtained with the remains of any American dinosaur known at the present time" (1914, p. 120) no longer holds, as *Nodosaurus* rivals it completely. They may, however, be congeneric (see below).

TAXONOMY AND RELATIONSHIPS.

Superorder Dinosauria Owen.
Order Ornithischia Seeley=Predentata Marsh.
Suborder Stegosauria Marsh. Plated dinosaurs.
Family Nodosauridæ Marsh 1890.

Family characteristics.—Quadrupedal dinosaurs with heavy dermal armor, vertebræ somewhat procœlous or amphiplatyan, with low neural arches, presacrals tending to ankylose with each other and with the ribs. Ilia broadened horizontally. Pelvis and posterior presacrals united with the overlying armor to form a carapace; limbs massive, fore limbs relatively large, digits five in manus and four in pes, terminating in broad unguals. Distinguished from the Stegosauridæ principally in that the latter have upstanding armor plates and caudal spines.

Genera: *Nodosaurus* and *Stegopelta,* Benton, Cretaceous; *Hoplitosaurus,* Dakota; *Hierosaurus,* Niobrara; *Ankylosaurus,* Edmonton and Lance. Also a close ally, if not actually included in the family, *Polacanthus,* of the European Wealden.

Re-definition of Nodosaurus Marsh.—Armor consisting of nodule-bearing plates, intercostals, separated over the torso by rows of smaller costal plates, armor of pelvis apparently limited to sacral region, not extending over the ilia. Oval keeled and spined plates, as well as

subdermal ossicles, the last bearing a characteristic textile appearance, also present. Skull and neck region unknown.

Relationships with other genera.—This genus was first described in 1889 and therefore takes priority over every other genus of plated dinosaurs in North America, save only the aberrant *Stegosaurus,* to which it is but remotely related. As the type is now made known as fully as may be, it must be the point of departure for all subsequent description of the related genera. Of these, *Hierosaurus* Wieland shows no point of generic distinction, as the common elements of each specimen are nearly identical. The latter genus is founded on very uncharacteristic material and is of questionable generic differentiation; specifically the form *H. sternbergi* is doubtless distinct.

Hoplitosaurus Lucas again is based upon insufficient material for absolute distinction from *Nodosaurus,* as in the armor the elements common to both types are essentially similar. The femora differ mainly in the form of the great trochanter, but as this is somewhat conjectural in *Nodosaurus,* there may not be even here a very marked distinction. *Nodosaurus textilis* and *Hoplitosaurus marshi,* while very nearly the same size, are again surely specifically distinct, and possibly generically, although closely related.

Stegopelta Williston differs from *Nodosaurus* in its much smaller size, but especially in the development of the armor over the ilia, in which there is so close a union that the two are inseparable. The armor consists of closely united but clearly defined hexagonal plates, each with a low eminence which is, however, occasionally almost obliterated by a more or less circular and irregularly placed depression which may have been the seat of a spine-like element. In the character of these iliac armor plates *Stegopelta* seems to be unique.

With *Ankylosaurus* Brown, on the other hand, a very close relationship apparently existed, some of the evidence for which I am not at liberty to publish through courtesy to Mr. Barnum Brown, whose discovery of this interesting type gives him prior descriptive rights. There are, however, certain characters which render them generically distinct, but I see no reason for excluding *Nodosaurus* from the direct ancestry of *Ankylosaurus,* nor the latter from the family Nodosauridæ, the description of which preceded that of the Ankylosauridæ of Brown by nearly a score of years. Brown says (1908, p. 190):

"The fragmentary skull of *Stereocephalus* Lambe does not show generic distinctions from the present specimen [type of *Ankylosaurus magniventris* Brown], as far as can be judged from the figures and description, but it is much smaller, and apparently the plates are not as symmetrical. It was found in the Belly River beds of Canada, an earlier horizon than the Hell Creek [Lance] beds, and is probably ancestral to *Ankylosaurus.*"

To what extent Brown will revise this opinion in the light of his recently discovered ankylosaur material from the Edmonton series, one can not say, nor is it possible to compare *Stereocephalus* with *Nodosaurus,* as homologous elements are as yet unannounced. The same may be said of *Paleoscincus* Leidy.

Of the Old World forms, *Polacanthus,* with its very perfect lumbar-hip carapace, is clearly the most suggestive of *Nodosaurus,* possibly because of the fine preservation of the most characteristic element, the pelvis. The latter, seen from below, has been very useful in the reconstruction and interpretation of that of *Nodosaurus,* but the very perfection and extent of the armor, covering as it does the entire posterior presacral and pelvic regions, so that the outline of the ilia is scarcely perceptible, is a marked distinction from the condition of armor development found in *Nodosaurus. Polacanthus* in this regard is more suggestive of *Stegopelta* than of *Nodosaurus.* It is undoubtedly of the same lineage as the American forms, but probably not directly ancestral to *Nodosaurus,* unless there has been a secondary reduction of the hip armature in the latter.

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DESCRIPTION OF PLATES I TO IV.

Pl. I.—*Nodosaurus textilis*. Holotype. Cat. No. 1815, Y. P. M. Fig. 1, dorsal vertebræ and armor, superior aspect. Fig. 2, oblique lateral aspect of the same. Both × about 2/9. Fig. 3, complex of ribs and dorsal armor, superior aspect; proximal end to the right; × about 1/6. Fig. 4, keeled armor plate, external aspect; × about 2/9. Fig. 5, ca. caudal 4, right aspect; × about 2/9.

a, armor; *b*, actual bone of centrum; *c*, centrum; *cp*, costal armor plates; *icp*, intercostal plate; *m*, matrix impression of centrum; *np*, neural plate; *pr*, prezygapophysis; *r*, rib; *s*, spinous process summit; *sd*, subdermal scutes; *t*, transverse process; *tcn*, tendon; × and dotted line, restoration.

Pl. II.—Pelvis of *Nodosaurus textilis*. Holotype. Cat. No. 1815, Y. P. M. Dorsal aspect, showing overlying sacral armor. × 1/8. *d*, diapophysial lamina; *np*, neural armor plate; *r*, *rib* impression; *s*, summit of spinous process.

Pl. III.—Pelvis of *Nodosaurus textilis*. Holotype. Cat. No. 1815, Y. P. M. Ventral aspect. × 1/8. *a*, acetabulum; *i*, ischiatic peduncle; *p*, pubic peduncle; *r*, rib impression; *sr*, sacral rib.

Pl. IV.—*Nodosaurus textilis*. Holotype. Cat. No. 1815, Y. P. M. × about 1/6. Fig. 1, posterior caudal (31), right aspect. Fig. 2, right ulna, oblique inner view. Fig. 3, right radius. Fig. 4, left femur, anterior aspect. Fig. 5, left tibia and proximal portion of fibula.

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Fig. [illegible] Heads of [illegible] Hootype [illegible] Cat. No. 1817, Y. P. [illegible] [illegible] peduncle; p, [illegible] [illegible]

[illegible] Cat. No. 1815, Y. P. M. [illegible] Fig. 2, right [illegible] lower, anterior aspect [illegible] of plate.

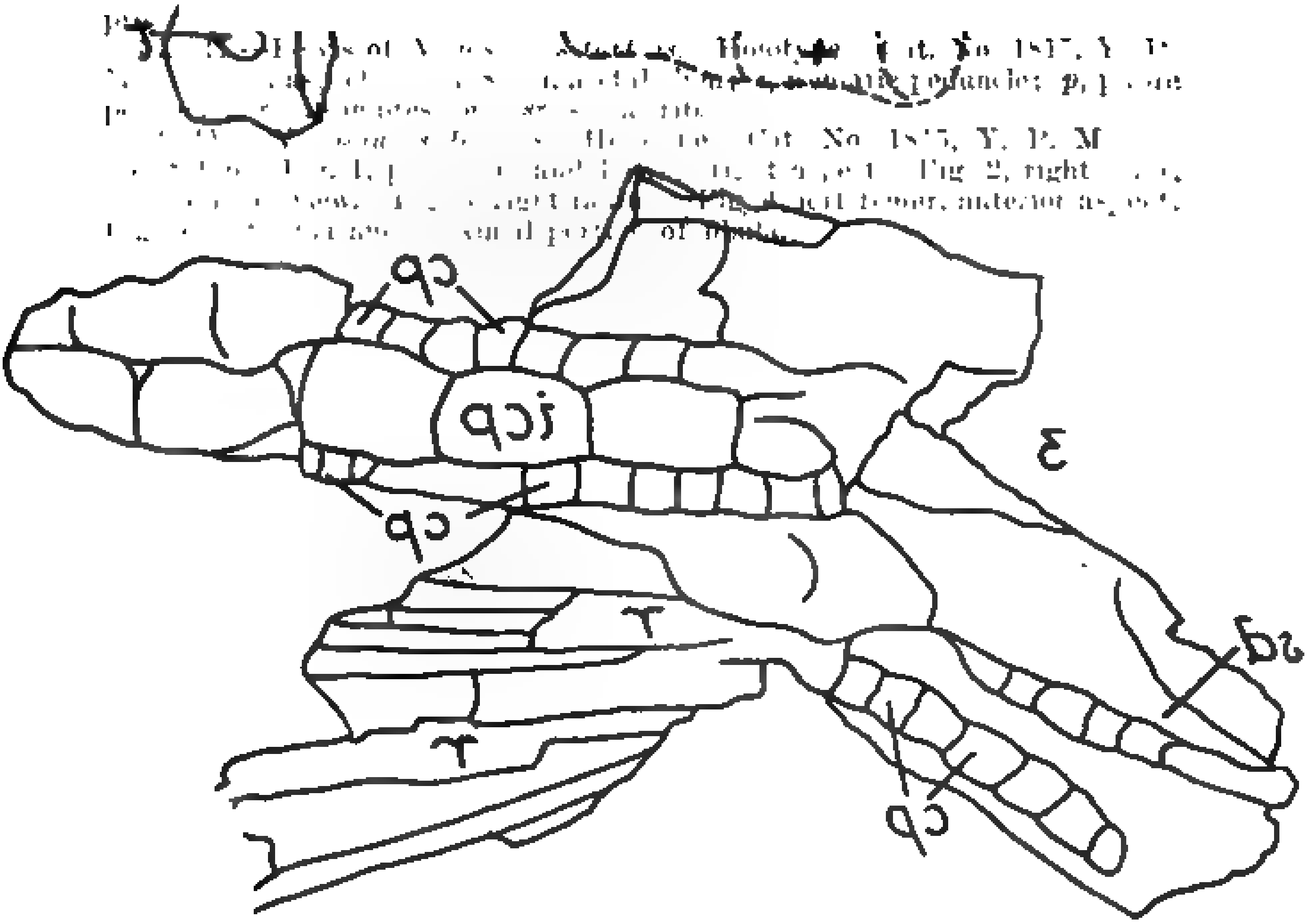

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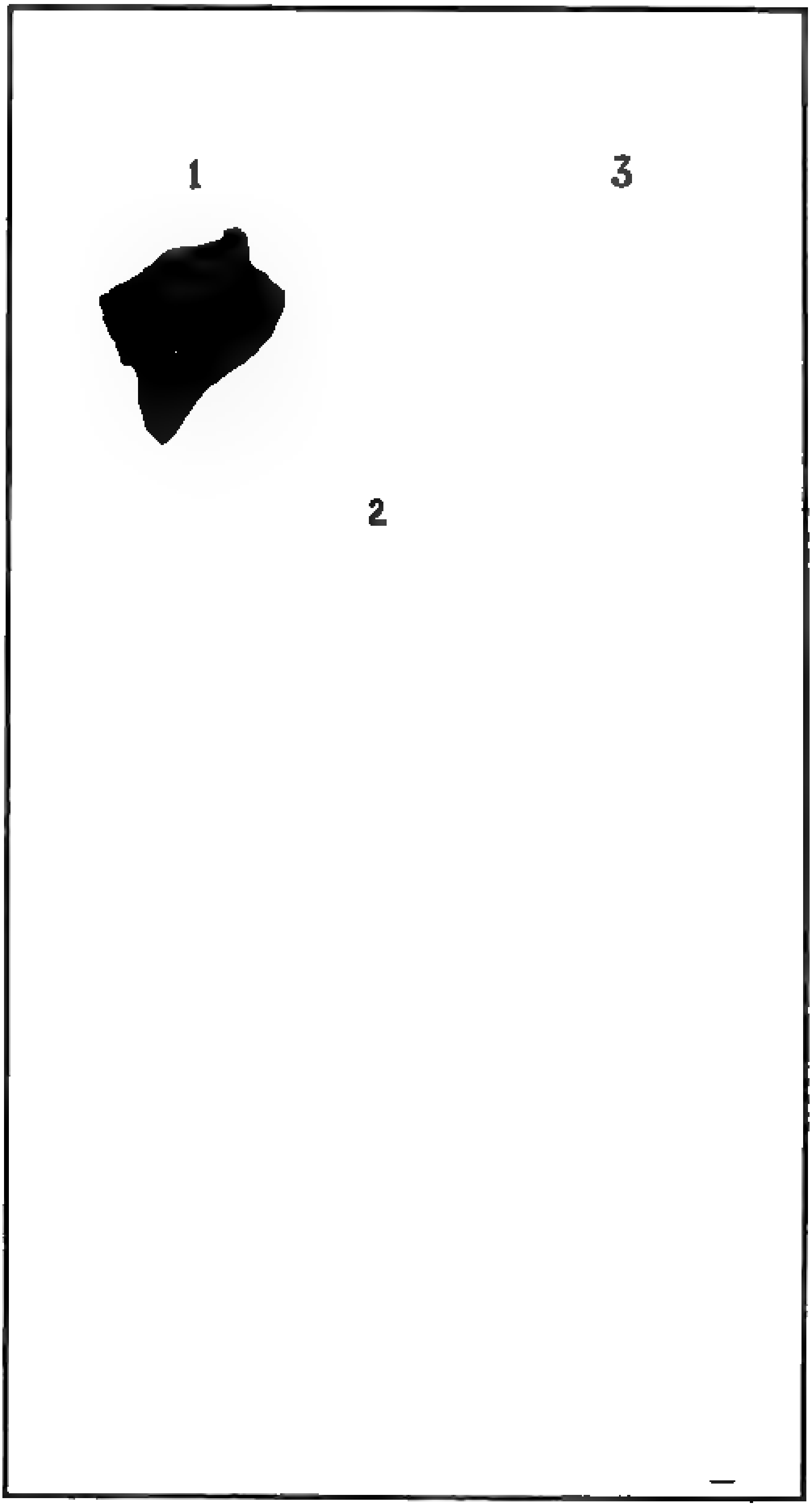
Plate III.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ART. VIII.—*An Outline of the Application of the Theory of Space Groups to the Study of the Structure of Crystals;* by RALPH W. G. WYCKOFF.

The theory of space groups[1] defines *all* of the ways of symmetrically arranging points in space. It thus supplies the basis upon which an entirely general method for the study of the structures of crystals can be built. Such a method has been in the course of development for several years; in its earlier stages it was used by Nishikawa in studying spinel[2] and other crystals, and has been employed by the writer[3] for the last three years. It has now reached a degree of completeness such as to be generally applicable to the problem of determining complicated structures of crystals.[4] A large amount of material, which is for the present purposes quite extraneous, is involved in the *development* of the theory of space groups. The present paper is an attempt to present only those details which are required in order that the *results* of this theory may be immediately applicable to the determination of the structure of crystals. It has been written with special reference to the accompanying determination of the structure of magnesium oxide.[5]

Entirely independently of this development, various authors[6] have commented upon the connection between the space groups and the structures of crystals as deduced from their effects upon X-rays. Niggli has recently made quite an extended application to the determination of crystal structures.[7]

The great advantage in using space groups lies in the

[1] L. Sohncke, Entwickelung einer Theorie der Krystallstruktur (1879); E. Federov, Z. Kryst., 24, 209, 1895; A. Schönflies, Krystallsysteme und Krystallstruktur, 1891; W. Barlow, Z. Kryst., 23, 1, 1894. Federov's work appeared in Russian before any of the other contributions. The last three studies are compared by H. Hilton, Mathematical Crystallography, 1903.

[2] S. Nishikawa, Proc. Tokyo Math. Phys. Soc., 8, 199, 1915.

[3] Ralph W. G. Wyckoff, J. Am. Chem. Soc., 42, 1100, 1920; Phys. Rev., (2), 16, 149, 1920; this Journal, 50, 317, 1920.

[4] A more orderly discussion of the entire method will probably appear shortly in book form.

[5] Ralph W. G. Wyckoff. See the following article.

[6] Such as A. Schönflies, Z. Kryst., 54, 545, 1915; A. Johnsen, Physik. Z., 16, 269, 1915.

[7] P. Niggli, Geometrische Krystallographie des Discontinuums, 1919. His development is not, however, entirely complete, and is carried out from a point of view which does not seem to be the simplest and best for the determination of the structure of crystals.

fact that if in a particular case the number of molecules associated with the unit of structure[8] and the symmetry are known, *all* of the possible atomic arrangements can be written down and considered in the light of further X-ray measurements. It can then be told, with a given amount of experimental data, whether the particular structure under examination can or can not be *uniquely defined.*

The Theory of Space Groups.[9]

The geometrical theory of space groups can be developed in the following way. If all of the *n operations* of symmetry that are characteristic of some one of the thirty-two classes of crystal symmetry are made to operate upon a point in space, *n* points will result which are all crystallographically equivalent. The *n equivalent points* arising from the operations of symmetry of one of the crystal classes, or these operations themselves, can be taken to define one of the thirty-two *point groups.* To take a simple example: the holohedry of the monoclinic system possesses two elements of symmetry, a 180° axis which will be taken to coincide with the Z-axis and a plane of symmetry at right angles to this axis (the XY plane). If these two elements of symmetry are caused to operate upon *any* point in space, three other crystallographically *equivalent* points will result. The four symmetry operations are (using Schönflies'[10] notation):

$$1, \qquad A(\pi), \qquad S_h, \qquad A(\pi)\,S_h \qquad \text{where}$$

1 (the identity) may be thought of as a rotation of 2π,
$A(\pi)$ is a rotation of angle π,
S_h is a mirroring against the horizontal (XY) plane and the *product* $A(\pi)S_h$ is the combination of the rotation $A(\pi)$ and the mirroring S_h. 1 and $A(\pi)$ correspond to the operation of the 180° axis, S_h and $A(\pi)S_h$ are mirrorings of 1 and A_h in the XY-plane. In figure 1 where Z is the 180° axis and XY the mirroring plane,

[8] This, of course, can be told from X-ray spectroscopy.

[9] In descriptive crystallography we are accustomed to consider the elements of symmetry—axes, planes and centers—to be of chief importance. For studying the internal structure of crystals, at least, it is much better to think of particular grouping of points (or atoms) as characterizing the different classes of symmetry. The elements of symmetry of these various arrangements then become interesting, but for most purposes unnecessary and complicating, details. Those who are well versed in the more customary crystallography are asked to read the following discussion from this other point of view, forgetting for the time being all associations with planes, axes and the like, except as they may be introduced into the argument.

[10] A. Schönflies, op. cit.

P is *any* point xyz. The other equivalent points $P_1\,(\bar{x}\bar{y}z)$, $P^2\,(x\bar{y}\bar{z})$ and $P_3\,(\bar{x}\bar{y}\bar{z})$ result from P by the forenamed operations[11] Similarly the equivalent points of each of the other thirty-one point groups can be obtained from their characteristics of symmetry. The five point groups having cubic symmetry are

	Symbol[12]	Schönflies,	Class of Symmetry Dana,	Groth	No. of Equivalent Points
1.	T	Tetartohedry	Tetartohedral	Pentagonal dodecahedral	12
2.	T_h	Paramorphic hemihedry	Pyritohedral	Dyakistetrahedral	24
3.	T_d	Hemimorphic hemihedry	Tetrahedral	Hexakistetrahedral	24
4.	O	Enantimorphic hemihedry	Plagiohedral	Pentagonal icositetrahedral	24
5.	O_h	Holohedry	Normal	Hexakisoctahedral	48

An extended arrangement of points in space which will have the symmetry of one of the crystal classes can be obtained by arranging these *point groups* according to some regular pattern which will itself have the total symmetry of the crystal system; such an extended arrangement of points in space is a *space group*. All of the centers of the point groups arranged according to one of these regular patterns are points of what is termed a *space lattice.* Fourteen *space lattices* have been shown to be crystallographically possible: one underlying all triclinic crystals, two possible monoclinic lattices, four orthorhombic, two tetragonal, two hexagonal, and three cubic. If the principal axes of symmetry of the lattice are taken as coordinate axes, each lattice can be defined by giving the translations along these axes which, applied to one point of the lattice, will give every other. The three cubic lattices are

[11] $\bar{x}$ is written for -x, etc.

[12] Unless otherwise noted, the notation that will be used is precisely that of Schönflies. Point groups are designated by capital letters, either alone or with subscripted numerals and elevated small letters. A particular case, to be discussed in detail shortly, will perhaps make the reason for this notation clear. The holohedry of the monoclinic system (C_2^h) is one of the *cyclic* groups, its principal axis of symmetry is *two-fold* and it has a *horizontal* plane of symmetry. In other words, the capital letter refers to the type of group, the numeral to the nature of the principal axis, and the small letter (except *i* for inversion) to the position of the principal plane of symmetry. In an analogous fashion the space groups that are isomorphous with this point group are written C_{2h}^1, C_{2h}^2, and so on.

Name	Symbol	Translations
1. Simple cubic	Γ_c	$\pm m2\tau_x, \pm n2\tau_y, \pm p2\tau_z$.

where $\tau_x = \tau_y = \tau_z$ in length and are translations along the axis of the subscript; m, n, and p are any integers or zero. When $m=n=p=1$, the translations are *primitive translations* and locate the adjacent points of the lattice.

2. Body-centered cubic	Γ_c''	$2\tau_x; 2\tau_y; 2\tau_z; \tau_x, \tau_y, \tau_z$.[13] (primitive)
3. Face-centered cubic	Γ_c'	$\tau_x, \tau_y; \tau_y, \tau_z; \tau_z, \tau_x$. (primitive).

As an example of the space and analytical representation of a space group, a simple group having the symmetry of the holohedry of the monoclinic system (designated C_{2h}^1) will be considered. The point group has already been described as having the following equivalent points:

$$xyz, \quad \bar{x}y\bar{z}, \quad \bar{x}\bar{y}\bar{z}, \quad x\bar{y}z.$$

The lattice underlying this space group is the simple monoclinic lattice (Γ_m) having the primitive translations $2\tau_x$, $2\tau_y$, $2\tau_z$. This space group is obtained by placing the point group C_2^h, unchanged, at each point of the lattice. If we choose some point of the lattice, O of figure 3, as the origin, then the coordinates of the points of the group about A, which is the lattice point obtained by the primitive translation $2\tau_x$, are (from the same origin):

$$x+2\tau_x, y, z;\ 2\tau_x - x, \bar{y}, z;\ 2\tau_x - x, \bar{y}, \bar{z};\ x+2\tau_x, y, \bar{z}.$$

In a similar way the coordinates of *equivalent points* about neighboring points of the lattice, and in general about any point of the *space group* C_{2h}^1, are given by one of the following sets:

$$\begin{aligned} &x\pm 2m\,\tau_x,\ y\pm 2n\,\tau_y,\ z\pm 2p\,\tau_z;\\ &\pm 2m\,\tau_x - x,\ \pm 2n\,\tau_y - y,\ z\pm 2p\,\tau_z;\\ &\pm 2m\,\tau_x - x,\ \pm 2n\,\tau_y - y,\ \pm 2p\,\tau_z - z;\\ &x\pm 2m\,\tau_x,\ y\pm 2n\,\tau_y,\ \pm 2p\,\tau_z - z, \end{aligned}$$

where m, n, and p are any whole numbers, including zero.

The 230 space groups, which are *all* of the possible ways of arranging points in space so that the resulting whole will have crystallographic symmetry, can be obtained in part by distributing the point groups themselves according to the lattices of corresponding symmetry; the rest by distributing in a similar manner groups of points which are developed with the aid of such elements of symmetry as "glide planes" or "screw axes."

Every crystal considered as an orderly arrangement

[13] According to the notation of Schönflies the composite translation having the components τ_x, τ_y, τ_z is represented by $\tau_x + \tau_y + \tau_z$.

of atoms must correspond with some space group and may be thought of as resulting from the regular arrangement in space of a large number of small groupings of atoms, all alike in size and shape. These small groupings, which we shall call for convenience "crystal molecules," can be built up by the superposition of several sets of *equivalent points,* which, then, repeat themselves according to some one of the fourteen space lattices. For instance, consider the compound AB. If the atom

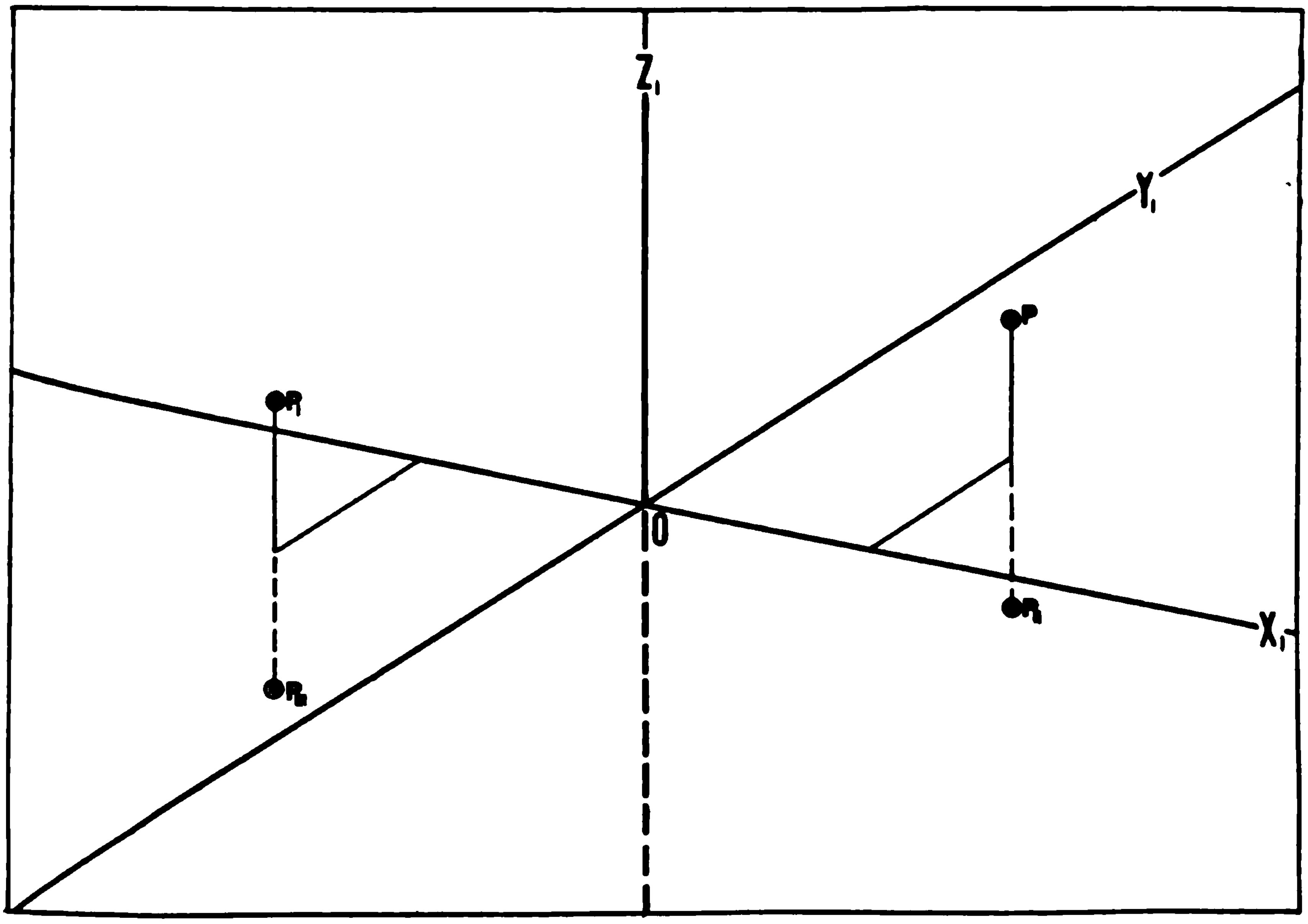


FIG. 1.—The monoclinic point group C_2^h (holohedry). P $(x\ y\ z)$, P$_{,}$ $(\bar{x}\ \bar{y}\ z)$, P$_{,,}$ $(x\ y\ \bar{z})$, and P$_{,,,}$ $(\bar{x}\ \bar{y}\ \bar{z})$ are equivalent points.

A occurs at the point (xyz) it must also appear at each one of the other n-1 equivalent points of that group. The atoms of B must occupy other n points in space, one of which will be $(x_1\ y_1\ z_1)$. Either of these groups of equivalent points, when repeated according to a suitable lattice, would form a space group; taken together, these groups of equivalent points define a *crystal molecule.* Such *crystal molecules,* when placed at the points of a lattice, yield a structure which represents the positions of the atoms in a crystal.

There is a slightly different and, for the determination of crystal structure, perhaps more usable way of looking

at the space groups and at the structure of crystals. A crystal, or the space grouping, may be divided into units of structure, unit parallelopipeds, which are all alike and similarly oriented, by planes passing through the principal directions of symmetry (fig. 2) parallel to the axes of coordinates. Thus, if the crystal is monoclinic, it would be divisible into monoclinic prisms; if it is cubic, the units are cubes, and so on. The planes bounding these units pass through points of the lattice and the

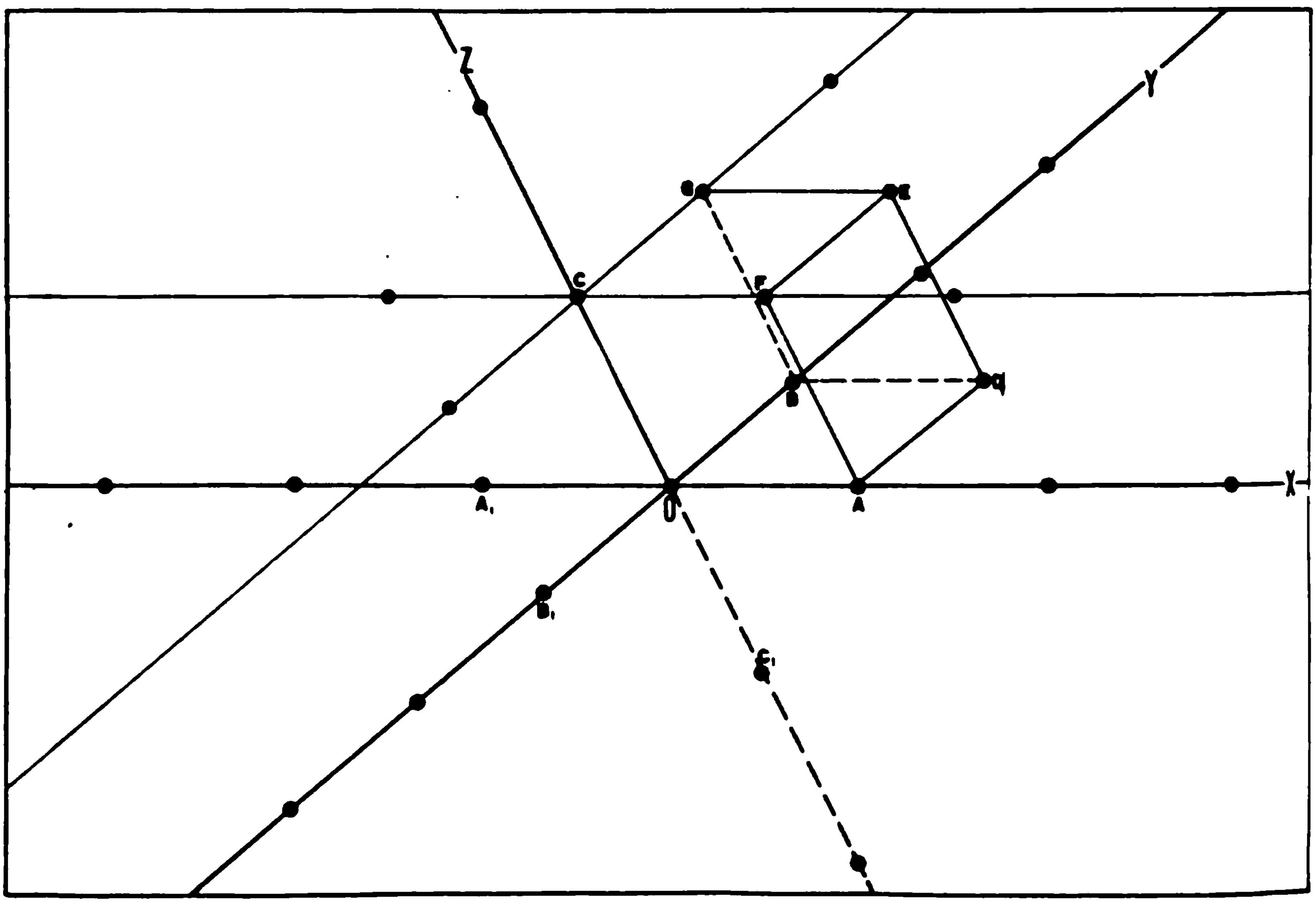


FIG. 2.—A portion from a space lattice. The black circles represent points of the lattice. OA, OB, and OC are translations of + 2 τ_x, + $2\tau_y$, and + $2\tau_z$ respectively. OADBGCFE is the unit prism.

resulting unit will contain anywhere from one to four "crystal molecules" depending upon the nature of the lattice. In figure 3 the monoclinic prism OAFCGBDE is a unit of structure of the space group C_{2h}^1. The eight points of the lattice at the eight corners of the unit prism together contrive to place within it a single crystal molecule.[14]

[14] This statement may be more readily seen on considering the following. If an atom of the crystal molecule which surrounds O (figure 3) lies inside of the unit it is impossible that the corresponding point of any other crystal molecule of the lattice can lie within this prism. Also the crystal molecules lying about the other seven corners of the unit will furnish within the unit the points corresponding to those about O which lie outside of the unit. Thus one crystal molecule is contained within the unit of structure.

The unit corresponding to the first cubic lattice is a simple cube with points of the lattice at its corners. The center of the single crystal molecule may be taken at O, the origin (figure 4b). The unit of structure for the body-centered cubic lattice (Γ_c'') is a cube having points of the lattice at its corners and center. It thus contains two crystal molecules, one having its center at the origin O, (000) and the other at the point $P_{,,,}$ (τ_x, τ_y, τ_z) fig. 4*c*. The face-centered unit (Γ_c') with points of the lattice at the corners and the centers of the faces of the unit cube, has four crystal molecules associated with it. Their centers are at the origin O, (000) and at the points P (0, τ_y, τ_z), $P_{,}$ (τ_x, τ_y, 0), $P_{,,}$(τ_x, 0, τ_z), fig. 4*d*.

This kind of a unit wherewith the crystal can be built up by simple translation of the unit involving only one coordinate axis at a time, is desired for the present purposes because calculations of relative spacings of like planes and of interference effects from different planes can be made upon it as typical of the crystal as a whole.

It is, then, essential to be able to write down the positions of all the atoms which lie within the unit prism. This can be done readily if the nature of the space group is known. If the unit is a simple prism having a single crystal molecule associated with it, then the atoms in the unit, of which the center of this molecule is a corner, can be represented by the coordinates of the atoms in the crystal molecule.[15]

The coordinates of the equivalent points in a unit prism for the space group C_{2h}^1 may consequently be written as

$$xyz, \qquad \bar{x}\bar{y}z, \qquad \bar{x}\bar{y}\bar{z}, \qquad xy\bar{z}.$$

If the unit has *n* crystal molecules associated with it, then of course it will contain *n* groups of equivalent points, that is, $n \times p$ equivalent points, if *p* is the number of equivalent points of the underlying point group. In the case of the space group C_{2h}^2 which is formed by placing a group of points having the symmetry of the point group C^h (holohedry of the monoclinic system) at each point of the second monoclinic lattice (symbol Γ'_m), the

[15] This will be clear if it is remembered that since neighboring points of the lattice are all alike, corresponding points of neighboring crystal molecules are identical. This leads to the fact that a translation along the X-axis of $-x$ is equal to the translation $2\tau_x - x$; likewise $-y = 2\tau_y - y$, and $-z = 2\tau_z - z$, where *y* and *z* are translations along the Y- and Z-axes.

unit prism will contain the following equivalent positions. The unit of groups having this lattice, with the primitive translations $2\tau_x$; τ_y , τ_z ; τ_y , $-\tau_z$, is best considered as a prism, two of whose sides are centered (figure 4a). There are then two crystal molecules in the unit. The coordinates of the equivalent positions are those of the equivalent points about a corner of the lattice (the origin) and those of the crystal molecule about a lattice point which is at the center of a side. Thus since the coordinates of this second *lattice point* are 0, τ_y , τ_z , the equivalent positions within the unit prism are:

$$xyz\,;\qquad x\bar{y}\bar{z}\,;\qquad \bar{x}\bar{y}\bar{z}\,;\qquad xy\bar{z}\,;$$

$$x, \tau_y+y, \tau_z+z;\ \bar{x}, \tau_y-y, \tau_z+z;\ \bar{x}, \tau_y-y, \tau_z-z;\ x, \tau_y+y, \tau_z-z.$$

The positions of the equivalent points in the unit of structure can be obtained in a similar manner for any space group.

The Significance of the Space Groups in the Study of the Structure of Crystals.—If an atom occurs at a general position x, y, z within the unit of structure, then in order that the conditions of symmetry may be fulfilled there must be as many more atoms of the same kind in the unit prism as there are *equivalent points.* For instance in the case of the holohedry of the cubic system the unit cube of a space group having the simple cubic lattice (Γ_c) as a basis has 48 equivalent positions contained within it; the unit cell of a space group having the face-centered lattice (Γ_c') with four points of the lattice (crystal molecules) associated with it, has 192 equivalent positions. In the first of these two cases, if an atom, say an oxygen atom, has a general position (xyz) within the cube, then there must be 47 other oxygen atoms of the same sort within the unit; or in the latter case there would have to be 191 other *similar* oxygen atoms.

In actual practice, for the present, we are dealing with simple compounds having relatively few atoms in the chemical molecule; X-ray spectrum measurements seem to indicate at the same time that only a small number of chemical molecules are associated with the unit cell. Consequently but few atoms of the same kind (less than the number of general equivalent positions) occur within the unit and, as a result, these atoms must take up special

positions such that two or more of the general equivalent points have the same position. If, for instance, the coordinates of a point in the unit are such that it lies in a plane of symmetry or on a trigonal axis, two or, in the second case, three sets of coordinates of the most generally placed equivalent points will coincide. In the case of the space group C_{2h}^1 (fig. 3) if z is made equal to τ_z, that is, to one half of the height of the unit prism, then the *four* equivalent points of the unit occupy *two* equivalent positions (M coincides with M″ and M′ with

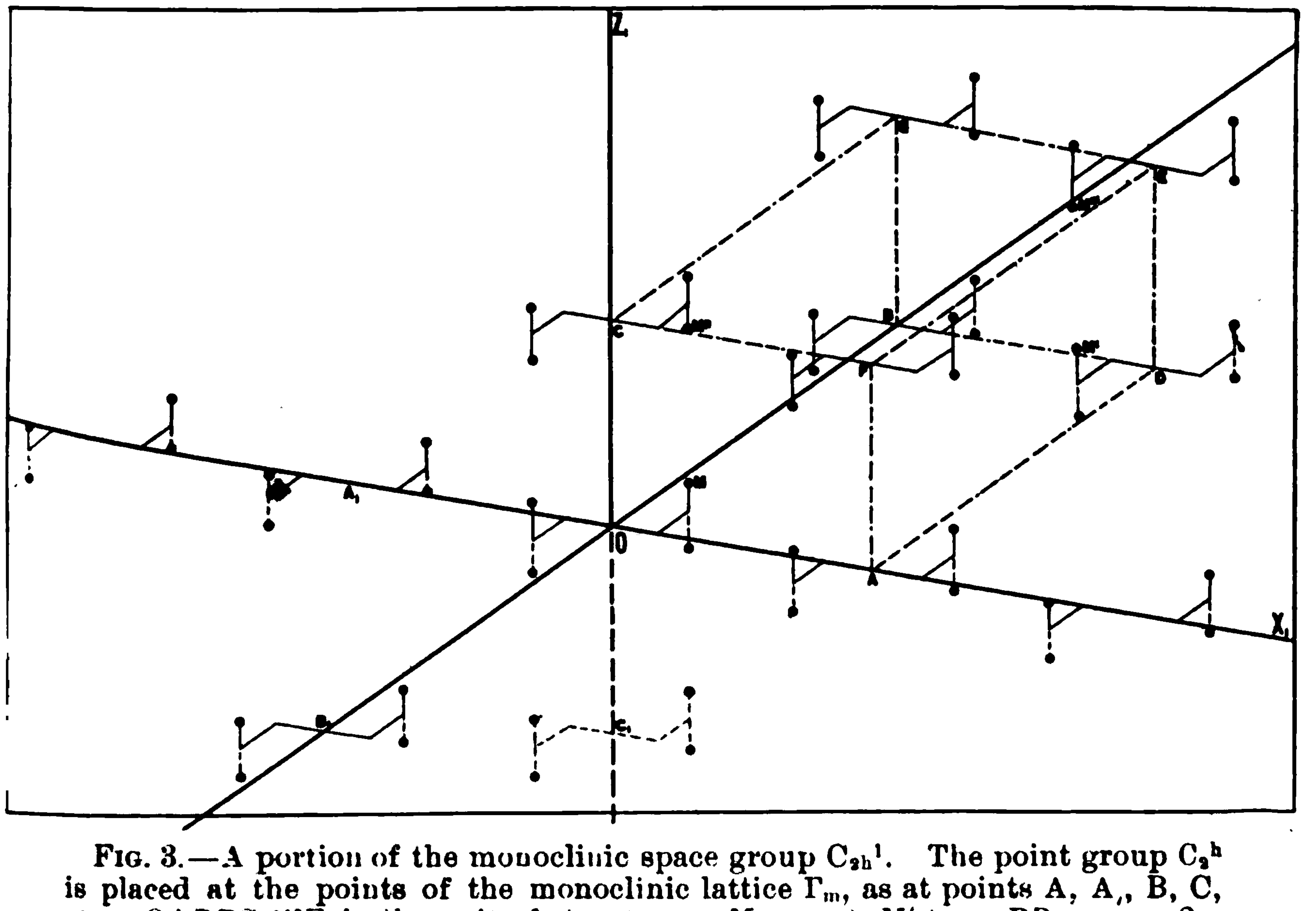


FIG. 3.—A portion of the monoclinic space group C_{2h}^1. The point group C_2^h is placed at the points of the monoclinic lattice Γ_m, as at points A, A,, B, C, etc. OADBGCFE is the unit of structure. M ($x\ y\ z$), M′ ($x =$ BD $- x = 2\tau_x - x = \bar{x}$; $y =$ AD $- y = 2\tau_y - y = \bar{y}$; z), M″ ($x\ y\ \bar{z}$), and M‴ ($\bar{x}\ \bar{y}\ \bar{z}$) are the equivalent points within the unit.

M‴). Again sodium chloride crystallizes in the holohedry of the cubic system. Since there are as many as 192 equivalent positions within the unit cube, there would in the most general case be as many as 192 sodium atoms and an equal number of chlorine atoms in the unit, if all the sodium atoms are alike and if all the chlorine atoms are also alike. X-ray spectrum measurements, however, seem to indicate that but four chemical molecules are associated in this case with the unit cell. If this is true, then, the sodium atoms and the chlorine atoms must

occupy such special positions that the 192 equivalent points reduce to four.

It is thus seen that with compounds which crystallize in the systems of higher symmetry, these special positions become of the utmost importance. A knowledge of *all* of these *special cases* is highly desirable as an aid in determining the structure of crystals. Niggli[16] records the simpler cases.[17]

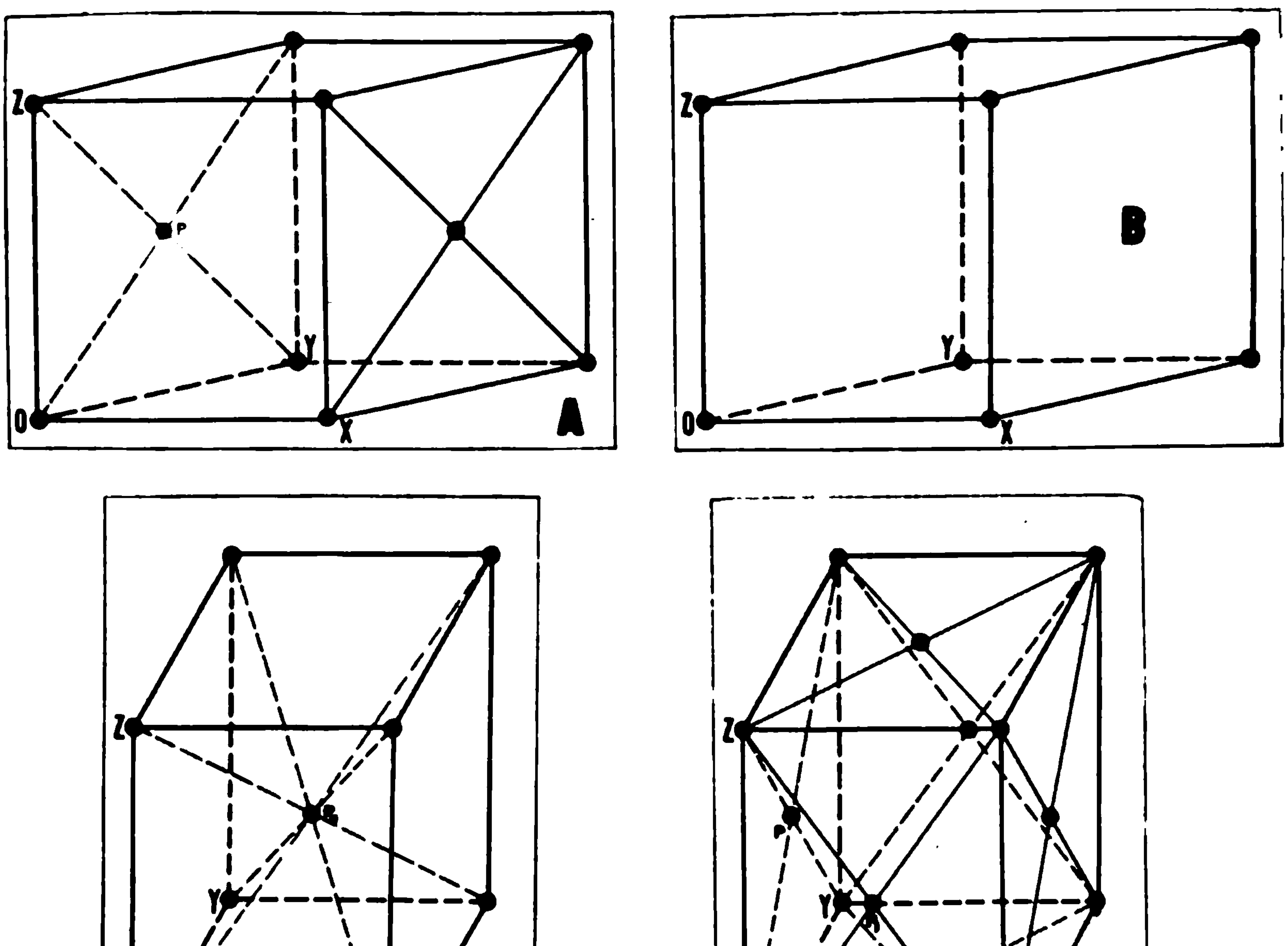


FIG. 4 (A).—The side-centered monoclinic unit of structure, Γ_m'. O (000) and P (0, τ_y, τ_z) are taken as the two points associated with the unit.

FIG. 4 (B).—The simple cubic unit of structure, Γ_c. O (000) may be taken as the single point of the lattice associated with the unit cube.

FIG. 4 (C).—The body-centered unit of structure, Γ_c''. O (000) and $P_{,,,}$ (τ_x, τ_y, τ_z) are the lattice points associated with the cube.

FIG. 4 (D).—The face-centered unit of structure, Γ_c'. O (000), P (0, τ_y, τ_z), $P_{,}$ (τ_x, τ_y, 0) and $P_{,,}$ (τ_x, 0, τ_y) are the lattice points associated with the unit.

[16] P. Niggli, op. cit.

[17] In the course of the development of a generally useful method for studying crystals, the writer has been engaged for some time in working out *all* of these special cases and expects to be able to present them in the near future. Some of the results to be given in the following paper are based upon this work.

The positions of the atoms in the *crystal molecule* are defined by having as many groups of equivalent points associated with each point of the lattice as there are kinds of *crystallographically different* atoms in the unit. This number will be as great as, and may be greater than, the number of different kinds of atoms in the *chemical molecule*. For instance, in the case of calcite[18] the positions of the carbon atoms must be assigned to at least one set of equivalent points, the positions of the calcium atoms to another set and the oxygen atoms to still another. With two chemical molecules associated with the unit cell, it might be conceivable for the two carbon atoms and the two calcium atoms to be alike and for all six of the oxygen atoms to be crystallographically alike, for four of them to be alike and two different,[19] or that there should be three sets of two like atoms or two sets of three that are alike. There might thus be as many as seven different groups of points associated with each unit of calcite.

The manner of obtaining, with the aid of the theory of space groups, *all* of the crystallographically possible ways of arranging the atoms of a compound in the fundamental unit has been illustrated in detail in dealing with calcite. So detailed an application of the theory to the case of magnesium oxide, which follows, is not possible here because of the large number of space groups that must be considered.

Summary.

Such details of the theory of space groups as are of importance in the application of this theory to the determination of the structure of crystals are briefly considered. Point groups, space lattices and space groups are illustrated by simple examples. The relations between space groups and crystals is discussed and those modifications in the results of the theory of space groups that are required in order that it may serve as the basis for a general method for the study of the structure of crystals, are indicated.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.
October, 1920.

[18] Ralph W. G. Wyckoff, this Journal, (4) 50, 317, 1920.
[19] Some of these possibilities are actually ruled out by considerations of symmetry.

Art. IX.—*The Crystal Structure of Magnesium Oxide;* by Ralph W. G. Wyckoff.

Previous measurements on powdered magnesium oxide[1] have led to the conclusion that this compound has the same crystal structure as sodium chloride. Such a study did not, however, furnish a unique solution. The following determination is based upon the general method for studying the structures of crystals which has been developed from the theory of space groups and which is given in a very general form in the preceding article.[2]

Fig. 1. The Laue photograph obtained by passing the X-rays in a direction roughly normal to the (100) face of magnesium oxide.

In the case of a cubic crystal there is no uncertainty as to the choice of those coordinate axes which will give the simplest unit of structure. The number of chemical

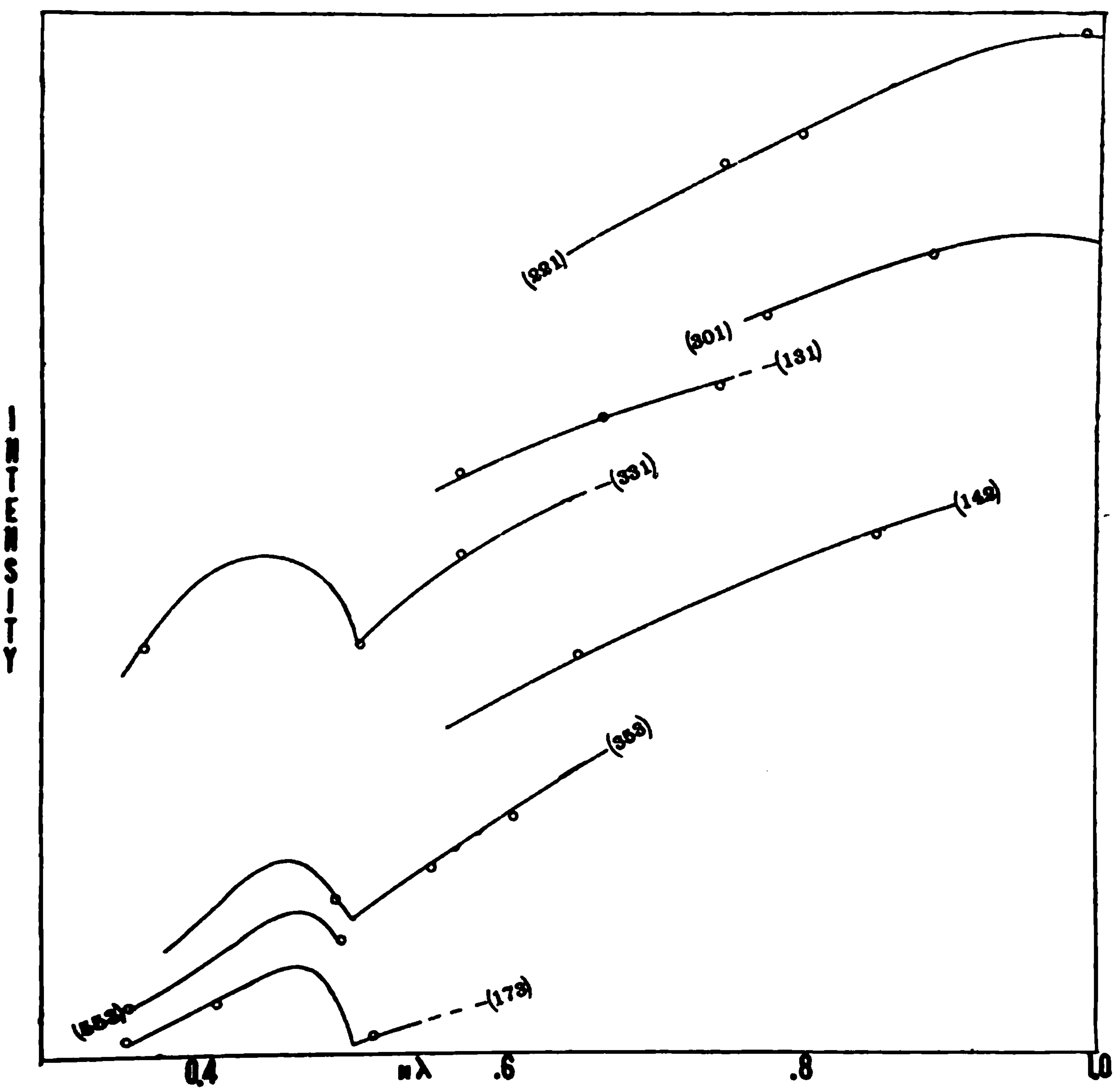
[1] W. P. Davey and E. O. Hoffman, Phys. Rev., (2), 15, 333, 1920.
[2] Ralph W. G. Wyckoff, see the preceding article in this number.

molecules associated with the unit cube of magnesium oxide was found in the usual manner from the density and a spectrum measurement from a principal face.

$$\frac{n^3}{m} = \left(\frac{2 \sin \theta}{\lambda}\right)^3 \frac{M}{\rho} \text{ where}$$

m = the number of molecules of MgO in the unit cube,
n = the order of the reflection,
λ = the wave length of the reflected X-rays,
θ = the angle of the reflection,
ρ = the density of MgO,
M = the weight of one molecule of MgO.

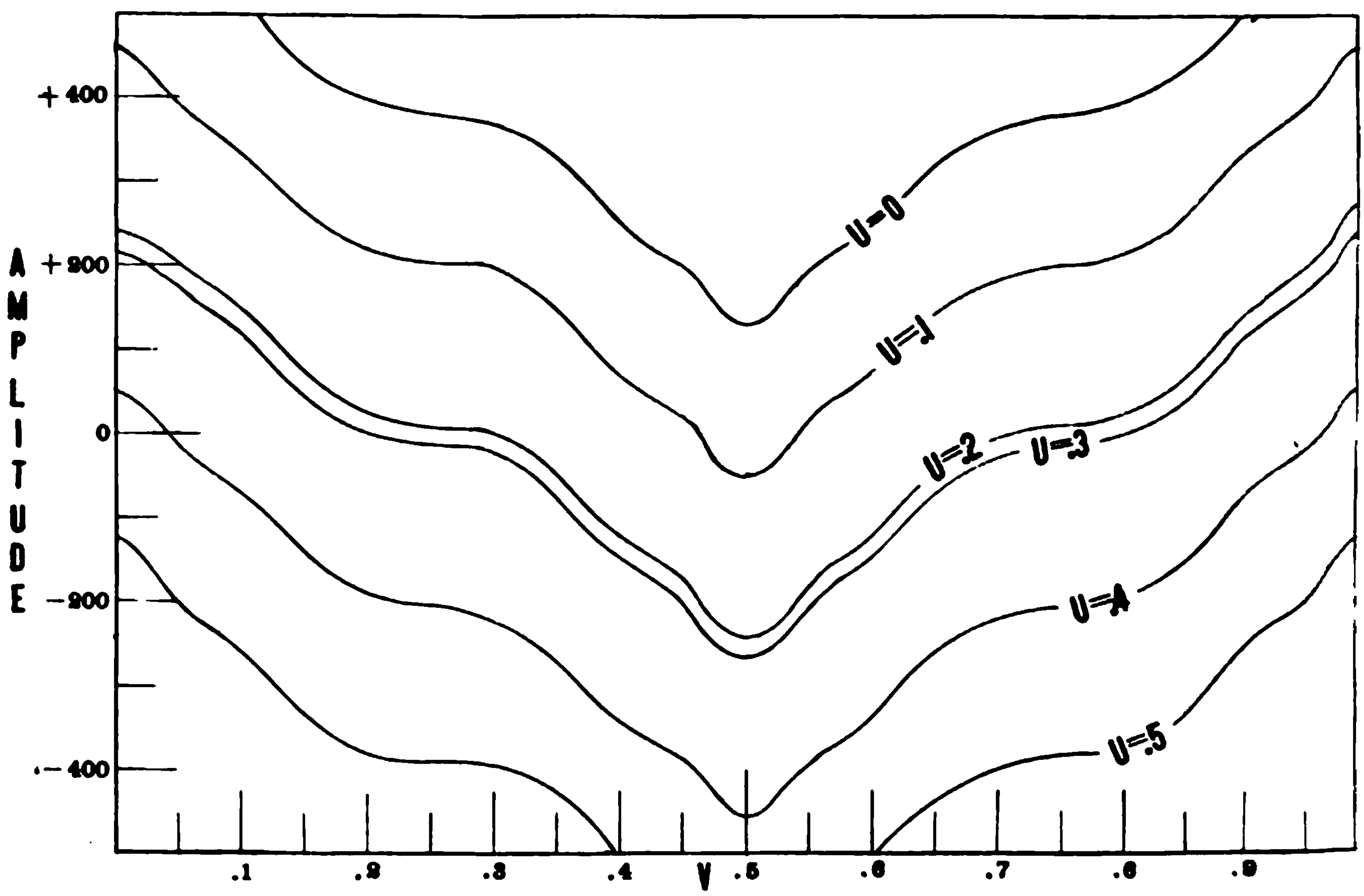
FIGURE 2.



Magnesium oxide crystallizes in the cubic system. From the meager data at hand, its symmetry seems to be holohedral; but for completeness any one of the five classes will be considered as possible. The number of

chemical molecules that it is possible to place in the unit cell is limited by the symmetry of the crystal. In the case of the normal cubic symmetry (holohedry) the greatest number of equivalent points (and equivalent atoms) to be expected in a unit cell is 192, since there are 48 equivalent points in the corresponding point group and there may be four points of the lattice associated with the unit of structure. Fewer than this number of molecules in the unit will result from atoms taking up special positions so that two or more of the equivalent positions coincide, and will consequently be whole numbers obtained by dividing 192 by two, three, or four, or by products

FIGURE 3.



of two, three, or four, into themselves or each other.[3] Possible values of the ratio $\frac{n'}{m}$ are listed in the following table:

[3] The holohedral structure contains planes of symmetry and two-, three-, and four-fold axes of symmetry. If a special position lies in a plane of symmetry, or on a two-fold axis, the number of equivalent positions will be reduced to one-half; if it lies on a three- or a four-fold axis, three or four equivalent points will occupy the same position.

m / n	1	2	3	4	6	8	12	16	24	32	48	64	96	192
1	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{6}$	—	—	—	—	—	—	—	—	—
2	8	4	$\frac{8}{3}$	2	$\frac{4}{3}$	1	$\frac{2}{3}$	$\frac{1}{2}$	—	—	—	—	—	—
3	27	$\frac{27}{2}$	9	$\frac{27}{4}$	$\frac{9}{2}$	$\frac{27}{8}$	$\frac{9}{4}$	$\frac{27}{16}$	$\frac{9}{8}$	—	—	—	—	—
4	64	32	$\frac{64}{3}$	16	$\frac{32}{3}$	8	$\frac{16}{3}$	4	$\frac{8}{3}$	2	$\frac{4}{3}$	1	—	—

Measurements from the (100) face of magnesium oxide, using the L-series lines of tungsten, gave a value for $\frac{n^3}{m}$ of 1.99. The unit cell must therefore contain either four or thirty-two chemical molecules of magnesium oxide.[4]

Assuming that $n=4$.—(1) All four of the oxygen atoms and of the magnesium atoms may be equivalent; (2) conceivably there might be two sets of two equivalent atoms; (3) three atoms might be alike and one different; or (4) two alike and the other two different one from the other. There seems to be no reason why either of the last two should be possible physically, but the second might be realized if magnesium oxide were polymerized into $(MgO)_2$ molecules in the crystal. All four possibilities will, however, be considered.

(1) If all four atoms of the same kind are equivalent, *all* of the space groups of the *cubic system* will reduce to the following arrangements:

(*a*) Mg: $0\,0\,0,\ \frac{1}{2}\,\frac{1}{4}\,\frac{3}{4},\ \frac{3}{4}\,\frac{1}{2}\,\frac{1}{4},\ \frac{1}{4}\,\frac{3}{4}\,\frac{1}{2}$.
O: $\frac{1}{2}\,\frac{1}{2}\,\frac{1}{2},\ 0\,\frac{3}{4}\,\frac{1}{4},\ \frac{1}{4}\,0\,\frac{3}{4},\ \frac{3}{4}\,\frac{1}{4}\,0$.

(*b*) Mg: $0\,0\,0,\ \frac{3}{4}\,\frac{1}{4}\,\frac{1}{2},\ \frac{1}{4}\,\frac{1}{2}\,\frac{3}{4},\ \frac{1}{2}\,\frac{3}{4}\,\frac{1}{4}$.
O: $\frac{1}{2}\,\frac{1}{2}\,\frac{1}{2},\ 0\,\frac{1}{4}\,\frac{3}{4},\ \frac{3}{4}\,0\,\frac{1}{4},\ \frac{1}{4}\,\frac{3}{4}\,0$.

These arrangements are obtained from the space groups O^6 and O^7 and consequently exhibit enantiomorphic hemihedry.

(*c*) Mg: $0\,0\,0,\ \frac{1}{2}\,\frac{1}{2}\,0,\ \frac{1}{2}\,0\,\frac{1}{2},\ 0\,\frac{1}{2}\,\frac{1}{2}$.
O: $0\,0\,\frac{1}{2},\ \frac{1}{2}\,0\,0,\ 0\,\frac{1}{2}\,0,\ \frac{1}{2}\,\frac{1}{2}\,\frac{1}{2}$.

(*c*) can be obtained from space groups of each of the five classes of cubic symmetry.

[4] If the crystal had tetartohedral symmetry, then the second possibility could be definitely eliminated.

$$(d)\ \mathrm{Mg}:\ 0\,0\,0,\ \tfrac{1}{2}\,\tfrac{1}{2}\,0,\ \tfrac{1}{2}\,0\,\tfrac{1}{2},\ 0\,\tfrac{1}{2}\,\tfrac{1}{2}.$$
$$\mathrm{O}:\ \tfrac{1}{4}\,\tfrac{1}{4}\,\tfrac{1}{4},\ \tfrac{1}{4}\,\tfrac{3}{4}\,\tfrac{3}{4},\ \tfrac{3}{4}\,\tfrac{1}{4}\,\tfrac{3}{4},\ \tfrac{3}{4}\,\tfrac{3}{4}\,\tfrac{1}{4}.$$

(*d*) results from groups having tetartohedral and tetrahedral symmetry.

$$(e)\ \mathrm{Mg}:\ u\,u\,u,\ \ u\,\bar{u}\,\bar{u},\ \ \bar{u}\,u\,\bar{u},\ \ \bar{u}\,\bar{u}\,u.$$
$$\mathrm{O}:\ v\,v\,v,\ \ v\,\bar{v}\,\bar{v},\ \ \bar{v}\,v\,\bar{v},\ \ \bar{v}\,\bar{v}\,v.$$

This arrangement also possesses either tetartohedral or tetrahedral symmetry.

$$(f)\ \mathrm{Mg}:\ u\,u\,u;\ u+\tfrac{1}{2},\ \tfrac{1}{2}-u,\ u;\ \ u,\ u+\tfrac{1}{2},\ \tfrac{1}{2}-u;$$
$$\tfrac{1}{2}-u,\ \bar{u},\ u+\tfrac{1}{2}.$$
$$\mathrm{O}:\ v\,v\,v;\ v+\tfrac{1}{2},\ \tfrac{1}{2}-v,\ \bar{v};\ \ \bar{v},\ v+\tfrac{1}{2},\ \tfrac{1}{2}-v;$$
$$\tfrac{1}{2}-v,\ v,\ v+\tfrac{1}{2}.$$

(*f*) has tetartohedral symmetry.

There are no space groups which can be specialized to give four sets of two like atoms and consequently (2) is impossible. For a similar reason (4) must be eliminated. There are two ways of meeting (3):

$$(g)\ \mathrm{Mg}:\ 0\,0\,0;\ \text{and}\ \tfrac{1}{2}\,\tfrac{1}{2}\,0,\ \tfrac{1}{2}\,0\,\tfrac{1}{2},\ 0\,\tfrac{1}{2}\,\tfrac{1}{2}.$$
$$\mathrm{O}:\ \tfrac{1}{2}\,\tfrac{1}{2}\,\tfrac{1}{2};\ \text{and}\ 0\,0\,\tfrac{1}{2},\ \tfrac{1}{2}\,0\,0,\ 0\,\tfrac{1}{2}\,0.$$
$$(h)\ \mathrm{Mg}:\ \tfrac{1}{2}\,\tfrac{1}{2}\,\tfrac{1}{2};\ \text{and}\ \tfrac{1}{2}\,\tfrac{1}{2}\,0,\ \tfrac{1}{2}\,0\,\tfrac{1}{2},\ 0\,\tfrac{1}{2}\,\tfrac{1}{2}.$$
$$\mathrm{O}:\ 0\,0\,0;\ \text{and}\ 0\,0\,\tfrac{1}{2},\ \tfrac{1}{2}\,0\,0,\ 0\,\tfrac{1}{2}\,0.$$

(*g*) is seen to be identical *in position* with (*c*). Both (*g*) and (*h*) can be derived from groups of any class of symmetry.

Assuming that $n = 32$.—There seems to be no method of deciding between the two possible values of n except one of trial. There are three different ways of arranging thirty-two molecules of magnesium oxide in the unit cell if all of the magnesium atoms are alike and if all of the oxygen atoms are also alike. If some of the chemically like atoms are assumed to be different crystallographically, as was just done when n was treated as equal to four, so large a number of possibilities arises that it is not feasible to consider each one in detail. Such arrangements are, however, highly improbable. The possible arrangements corresponding to (1) are as follows:

(*i*) **Mg**: $\frac{3}{8}\frac{3}{8}\frac{3}{8}$, $\frac{3}{8}\frac{5}{8}\frac{5}{8}$, $\frac{5}{8}\frac{3}{8}\frac{5}{8}$, $\frac{5}{8}\frac{5}{8}\frac{3}{8}$, $\frac{7}{8}\frac{7}{8}\frac{3}{8}$, $\frac{7}{8}\frac{1}{8}\frac{5}{8}$, $\frac{1}{8}\frac{7}{8}\frac{5}{8}$, $\frac{1}{8}\frac{1}{8}\frac{3}{8}$,
$\frac{7}{8}\frac{3}{8}\frac{7}{8}$, $\frac{7}{8}\frac{5}{8}\frac{1}{8}$, $\frac{1}{8}\frac{3}{8}\frac{1}{8}$, $\frac{1}{8}\frac{5}{8}\frac{7}{8}$, $\frac{3}{8}\frac{7}{8}\frac{7}{8}$, $\frac{3}{8}\frac{1}{8}\frac{1}{8}$, $\frac{5}{8}\frac{1}{8}\frac{7}{8}$, $\frac{5}{8}\frac{7}{8}\frac{1}{8}$,
$\frac{7}{8}\frac{7}{8}\frac{7}{8}$, $\frac{5}{8}\frac{7}{8}\frac{5}{8}$, $\frac{7}{8}\frac{5}{8}\frac{5}{8}$, $\frac{5}{8}\frac{5}{8}\frac{7}{8}$, $\frac{3}{8}\frac{3}{8}\frac{7}{8}$, $\frac{1}{8}\frac{3}{8}\frac{5}{8}$, $\frac{3}{8}\frac{1}{8}\frac{5}{8}$, $\frac{1}{8}\frac{1}{8}\frac{7}{8}$,
$\frac{3}{8}\frac{7}{8}\frac{3}{8}$, $\frac{1}{8}\frac{7}{8}\frac{1}{8}$, $\frac{3}{8}\frac{5}{8}\frac{1}{8}$, $\frac{1}{8}\frac{5}{8}\frac{3}{8}$, $\frac{7}{8}\frac{3}{8}\frac{3}{8}$, $\frac{5}{8}\frac{3}{8}\frac{1}{8}$, $\frac{7}{8}\frac{1}{8}\frac{1}{8}$, $\frac{5}{8}\frac{1}{8}\frac{3}{8}$.

O: $\frac{1}{8}\frac{1}{8}\frac{1}{8}$, $\frac{5}{8}\frac{5}{8}\frac{1}{8}$, $\frac{5}{8}\frac{1}{8}\frac{5}{8}$, $\frac{1}{8}\frac{5}{8}\frac{5}{8}$, $\frac{7}{8}\frac{7}{8}\frac{1}{8}$, $\frac{3}{8}\frac{3}{8}\frac{1}{8}$, $\frac{3}{8}\frac{7}{8}\frac{5}{8}$, $\frac{7}{8}\frac{3}{8}\frac{5}{8}$,
$\frac{7}{8}\frac{1}{8}\frac{7}{8}$, $\frac{3}{8}\frac{5}{8}\frac{7}{8}$, $\frac{3}{8}\frac{1}{8}\frac{3}{8}$, $\frac{7}{8}\frac{5}{8}\frac{3}{8}$, $\frac{1}{8}\frac{7}{8}\frac{7}{8}$, $\frac{5}{8}\frac{3}{8}\frac{7}{8}$, $\frac{5}{8}\frac{7}{8}\frac{3}{8}$, $\frac{1}{8}\frac{3}{8}\frac{3}{8}$,
$\frac{5}{8}\frac{5}{8}\frac{5}{8}$, $\frac{1}{8}\frac{1}{8}\frac{5}{8}$, $\frac{1}{8}\frac{5}{8}\frac{1}{8}$, $\frac{5}{8}\frac{1}{8}\frac{1}{8}$, $\frac{3}{8}\frac{3}{8}\frac{5}{8}$, $\frac{7}{8}\frac{7}{8}\frac{5}{8}$, $\frac{7}{8}\frac{3}{8}\frac{1}{8}$, $\frac{3}{8}\frac{7}{8}\frac{1}{8}$,
$\frac{3}{8}\frac{5}{8}\frac{3}{8}$, $\frac{7}{8}\frac{1}{8}\frac{3}{8}$, $\frac{7}{8}\frac{5}{8}\frac{7}{8}$, $\frac{3}{8}\frac{1}{8}\frac{7}{8}$, $\frac{5}{8}\frac{3}{8}\frac{3}{8}$, $\frac{1}{8}\frac{7}{8}\frac{3}{8}$, $\frac{1}{8}\frac{3}{8}\frac{7}{8}$, $\frac{5}{8}\frac{7}{8}\frac{7}{8}$.

This arrangement is a special case of the space group O^8.

(*j*) Mg: $u\,u\,u$; $u+\frac{1}{2}, u+\frac{1}{2}, u$; $u+\frac{1}{2}, u, u+\frac{1}{2}$; $u, u+\frac{1}{2}, u+\frac{1}{2}$;
$u\,u\,u$; $u+\frac{1}{2}, \frac{1}{2}-u, u$; $u+\frac{1}{2}, \bar{u}, \frac{1}{2}-u$; $u, \frac{1}{2}-u, \frac{1}{2}-u$;
$\bar{u}\,u\,u$; $\frac{1}{2}-u, u+\frac{1}{2}, u$; $\frac{1}{2}-u, u, \frac{1}{2}-u$; $\bar{u}, u+\frac{1}{2}, \frac{1}{2}-u$;
$u\,\bar{u}\,u$; $\frac{1}{2}-u, \frac{1}{2}-u, u$; $\frac{1}{2}-u, \bar{u}, u+\frac{1}{2}$; $u, \frac{1}{2}-u, u+\frac{1}{2}$;
$\bar{u}\,u\,u$; $\frac{1}{2}-u, \frac{1}{2}-u, \bar{u}$; $\frac{1}{2}-u, \bar{u}, \frac{1}{2}-u$; $\bar{u}, \frac{1}{2}-u, \frac{1}{2}-u$;
$u\,\bar{u}\,u$; $u+\frac{1}{2}, \frac{1}{2}-u, u$; $u+\frac{1}{2}, \bar{u}, u+\frac{1}{2}$; $u, \frac{1}{2}-u, u+\frac{1}{2}$;
$\bar{u}\,u\,u$; $\frac{1}{2}-u, u+\frac{1}{2}, u$; $\frac{1}{2}-u, u, u+\frac{1}{2}$; $u, u+\frac{1}{2}, u+\frac{1}{2}$;
$u\,u\,\bar{u}$; $u+\frac{1}{2}, u+\frac{1}{2}, \bar{u}$; $u+\frac{1}{2}, u, \frac{1}{2}-u$; $u, u+\frac{1}{2}, \frac{1}{2}-u$;

O: $v\,v\,v$; and 31 other positions as with Mg. u and v can have any values from zero to unity. This arrangement can be obtained from either the holohedry or from any of the classes of the hemihedry.

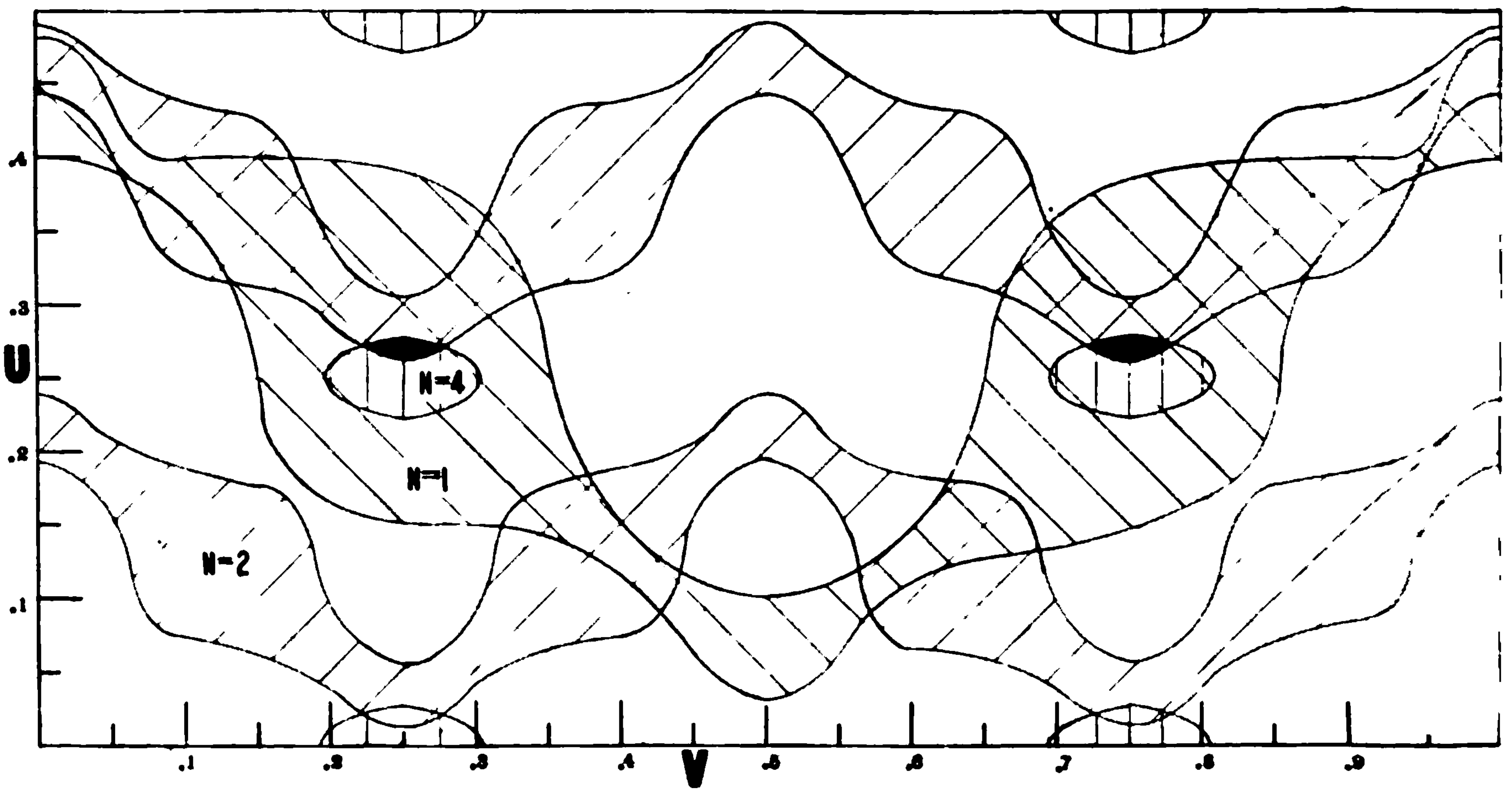
(*k*) Mg: $u\,u\,u$; $u+\frac{1}{2}, u, u+\frac{1}{2}$; $\frac{1}{4}-u, \frac{1}{4}-u, \frac{1}{4}-u$; $\frac{3}{4}-u, \frac{1}{4}-u, \frac{3}{4}-u$;
$u\,\bar{u}\,\bar{u}$; $u+\frac{1}{2}, \bar{u}, \frac{1}{2}-u$; $\frac{1}{4}-u, u+\frac{1}{4}, u+\frac{1}{4}$; $\frac{3}{4}-u, u+\frac{1}{4}, u+\frac{3}{4}$;
$\bar{u}\,u\,\bar{u}$; $\frac{1}{2}-u, u, \frac{1}{2}-u$; $u+\frac{1}{4}, \frac{1}{4}-u, u+\frac{1}{4}$; $u+\frac{3}{4}, \frac{1}{4}-u, u+\frac{3}{4}$;
$\bar{u}\,\bar{u}\,u$; $\frac{1}{2}-u, \bar{u}, u+\frac{1}{2}$; $u+\frac{1}{4}, u+\frac{1}{4}, \frac{1}{4}-u$; $u+\frac{3}{4}, u+\frac{1}{4}, \frac{3}{4}-u$;
$u+\frac{1}{2}, u+\frac{1}{2}, u$; $u, u+\frac{1}{2}, u+\frac{1}{2}$; $\frac{3}{4}-u, \frac{3}{4}-u, \frac{1}{4}-u$; $\frac{1}{4}-u, \frac{3}{4}-u, \frac{3}{4}-u$;
$u+\frac{1}{2}, \frac{1}{2}-u, \bar{u}$; $u, \frac{1}{2}-u, \frac{1}{2}-u$; $\frac{3}{4}-u, u+\frac{3}{4}, u+\frac{1}{4}$; $\frac{1}{4}-u, u+\frac{3}{4}, u+\frac{3}{4}$;
$\frac{1}{2}-u, u+\frac{1}{2}, \bar{u}$; $\bar{u}, u+\frac{1}{2}, \frac{1}{2}-u$; $u+\frac{3}{4}, \frac{3}{4}-u, u+\frac{1}{4}$; $u+\frac{1}{4}, \frac{3}{4}-u, u+\frac{3}{4}$;
$\frac{1}{2}-u, \frac{1}{2}-u, u$; $\bar{u}, \frac{1}{2}-u, u+\frac{1}{2}$; $u+\frac{3}{4}, u+\frac{3}{4}, \frac{1}{4}-u$; $u+\frac{1}{4}, u+\frac{3}{4}, \frac{3}{4}-u$.

O: $v\,v\,v$; and 31 other positions as with Mg. u and v again can have any values from zero to unity. This arrangement can be obtained from any but the tetartohedral and tetrahedral classes.

It would obviously be of considerable advantage to know to which class of crystal symmetry magnesium oxide should be assigned. There is, however, a certain amount

of doubt concerning the exact connection between the degree of symmetry as exhibited by the external form and especially by the etch figures and the internal arrangement of atoms. In the present instance there is no reason for believing that magnesium oxide is not holohedral. If this is true and if n really equals four, then its structure must be assigned to arrangement (c), or of course (g), on the basis of symmetry considerations alone. On account of the possible uncertainty, however, concerning the class of crystal symmetry to which magnesium oxide should be assigned, not only the holo-

FIGURE 4.



hedral arrangements but all of those exhibiting cubic symmetry will be compared with experiment.

The following *experimental data* are available for distinguishing between the possible structures for magnesium oxide. The results from the powder photographs[5] are said to be in entire agreement with the "sodium chloride arrangement" (c). Besides the reflection from the (100) face which was used in finding the amount of mass associated with the unit cube, a series of Laue photographs with the rays normal to the (100) face and inclined as small angles to this normal, was prepared. These photographs (fig. 1), some of which are the results of very long exposures and were prepared in order to give faint reflections a chance to register, were studied

[5] W. P. Davey and E. O. Hoffman, op. cit.

in the usual fashion.[6] A typical curve obtained by plotting the estimated intensities of reflection of the planes appearing in a single photograph against the wave lengths they are reflecting, is shown in figure 2. The important characteristics of these photographs are illustrated by the graph: *no* planes are found which give *any* first order reflection except those, all of whose indices are odd; and the second order reflections of planes giving both first and second order reflections are by far the stronger.

The interference effects to be expected from each of the possible arrangements of atoms can be calculated. The spacing between like planes in a simple cubic arrangement of points is

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

$a =$ the length of the side of the unit cube which can be told from the spectrum measurements and $d =$ the spacing between like planes whose Miller indices are h,k,l. The intensity of reflection from any plane (hkl) in the n^{th} order can be written in the usual manner.

$$\text{Intensity} \propto f\left(\frac{d}{n}\right) [A^2 + B^2],$$

Where A and B are cosine and sine terms to be evaluated in the particular cases; the form of the function of the spacing, $f\left(\frac{d}{n}\right)$, need not be assumed for the present purpose.

Possible arrangement (a).

It can be shown that this does not represent the structure of magnesium oxide because, while in the Laue photographs the only planes giving reflections in the first order have indices that are all of them odd, this grouping should give good reflections with planes whose indices are also two odd and one even.

Possible arrangement (b).

This can be eliminated for the same reason.

[6] Ralph W. G. Wyckoff, This Journal (IV) 50, 317 (1920).

Possible arrangement (c).

$$A = \overline{Mg}\,\{1+\cos\pi n\,(h+k)+\cos\pi n\,(h+l)+\cos\pi n\,(k+l)\}$$
$$+\overline{O}\,\{\cos\pi nl+\cos\pi nk+\cos\pi nh+\cos\pi n\,(h+k+l)\}.$$

$B = 0$. $\overline{Mg}$ and $\overline{O}$ represent the scattering powers of magnesium and of oxygen respectively.

In case h, k, and l are *all odd:*

When $n=1$, $A=4\overline{Mg}-4\overline{O}$; when $n=2$, $A=4\overline{Mg}+4\overline{O}$.

In case the indices are *two* of them *odd* and *one even:*

When $n=1$, $A=0$; when $n=2$, $A=4\overline{Mg}+4\overline{O}$.

In case the indices are *two even* and *one odd:*

When $n=1$, $A=0$; when $n=2$, $A=4\overline{Mg}+4\overline{O}$.

The results from the arrangement, which is the "sodium chloride arrangement," are seen to be in complete agreement with the experimental data as obtained from the Laue photographs and illustrated in figure 6.

Possible arrangement (d).

The calculations show that this arrangement also would have first order reflections only from planes with indices that are all odd. The second of such planes is in this case weaker than the first—a fact which is contrary to the experiment. Grouping (d) consequently must be ruled out of consideration.

Possible arrangement (e).

This and the next arrangement, (*f*), are most simply tested by comparison with the spacing measurements from simple faces (the results to be obtained with the spectrometer or by photographing the spectra). Trial was made by seeing whether values of u and v could be chosen so as to give results which would be in close agreement with those from (*c*). The reflections to be obtained from the (110) faces serve to eliminate (*e*). According to the experimental results—from the spectrum measurements and presumably also from the powder photographs—the intensity of the first order reflection from (110) is zero or practically zero. If u and v are the variable parameters for magnesium and for oxygen respectively, then the calculated first order from (110) may be represented by:

$$A = \overline{Mg}\{2+2\cos 4\pi u\}+\overline{O}\,\{2+2\cos 4\pi v\}.$$
$$B = 0.$$

At only one pair of values, u and v equalling ¼ and ¾, does A become zero. In this particular case the grouping is that of (c). If, however, u and v had values close to, but not equalling ¼ and ¾, the reflections from such an arrangement would be, with the present methods, indistinguishable from those from (c). It is nevertheless not probable as the structure of magnesium oxide since this compound appears to exhibit a higher degree of symmetry than that shown by (e).

Possible arrangement (f).

Plane (100)

$$A = \overline{Mg}\{2\cos 2\pi nu + 2\cos 2\pi n(u+\tfrac{1}{2})\} + \overline{O}\{2\cos 2\pi nv + 2\cos 2\pi n(v+\tfrac{1}{2})\}.$$
$$B = 0.$$

In the first order this becomes

$A=0$ and $B=0$ for all values of u and v.

Plane (110)

When $n=1$,

$$A = \overline{Mg}\{\cos 4\pi u + \cos\pi(1-4u)\} + \overline{O}\{\cos 4\pi v + \cos\pi(1-4v)\},$$
$=0$ for all values of u and v. $B=0$.

Plane (111)

When $n=1$,

$$A = \overline{Mg}\{\cos 6\pi u + 3\cos 2\pi u\} + \overline{O}\{\cos 6\pi v + 3\cos 2\pi v\}.$$

This term has in general a value other than zero and will be large or small depending upon the particular values chosen for u and v. Consequently especially with the present lack of quantitative knowledge about scattering, little difficulty would be experienced in accommodating a structure of this type, differing more or less from (c) according to the particular hypotheses regarding the amount of scattering, to the spectrometer measurements from these three faces. Use must therefore be made of the results from the Laue photographs. The A term for the amplitude of the reflection in the first order for planes having *one odd and two even indices* is as follows:

$$A = \overline{Mg}\{\cos 2\pi u(2m+2m_1+2m_2+1) - \cos 2\pi u(2m-2m_1-2m_2+1) + \cos 2\pi u(2m_1-2m-2m_2-1) - \cos 2\pi u(2m_2-2m_1-2m-1)\}$$
$+\overline{O}$\{a similar term in v\}, where m, m_1, and m_2 are integers.

For the present qualitative purpose the B term need not be considered. It is seen that there will *usually* be a

reflection from such a plane unless u and v have values such that the arrangement becomes identical with (c). If, however, u and v have values close to, but not equalling the coordinate positions of (c), then the intensity of reflection in this type of plane would be small enough to escape detection with the insensitive methods of observation that are now available. There is, consequently, no way to rule this arrangement completely out of consideration. It is, however, improbable because magnesium oxide itself gives no indications of tetartohedral symmetry.

Possible arrangement (g).

Since the positions of the atoms are the same as in the case of (c), it also fits the X-ray data.

Possible arrangement (h).

The reflections from planes all of whose indices are odd and from those having one even and two odd indices as calculated from this grouping are in agreement with the experimental results. The amplitude of the reflection in the first order for the planes having one odd and two even indices is not, however, equal to zero for this arrangement.

$$A=2\bar{O}-2\,Mg,\ B=0.$$

Since no such planes are found in the first order region from the Laue photographs, this grouping may be eliminated.

Possible arrangement (i).

If the origin is moved to the point ($\frac{1}{8}\ \frac{1}{8}\ \frac{1}{8}$), this arrangement is seen to be identical in the present instance with (c).

Possible arrangement (j).

Writing $a=h+k+l$, $b=h-k-l$, $c=k-h-l$, $d=l-h-k$, then

$$\begin{aligned} A=\bar{Mg}\{&2\cos 2\pi nua+2\cos 2\pi nub+2\cos 2\pi nuc+2\cos 2\pi nud\\ &+2\cos 2\pi n\,[ua+\tfrac{1}{2}(h+k)]+2\cos 2\pi n\,[ub+\tfrac{1}{2}(h+k)]\\ &+2\cos 2\pi n\,[uc+\tfrac{1}{2}(h+k)]+2\cos 2\pi n\,[ud+\tfrac{1}{2}(h+k)]\\ &+2\cos 2\pi n\,[ua+\tfrac{1}{2}(h+l)]+2\cos 2\pi n\,[ub+\tfrac{1}{2}(h+l)]\\ &+2\cos 2\pi n\,[uc+\tfrac{1}{2}(h+l)]+2\cos 2\pi n\,[ud+\tfrac{1}{2}(h+l)]\\ &+2\cos 2\pi n\,[ua+\tfrac{1}{2}(k+l)]+2\cos 2\pi n\,[ub+\tfrac{1}{2}(k+l)]\\ &+2\cos 2\pi n\,[uc+\tfrac{1}{2}(k+l)]+2\cos 2\pi n\,[ud+\tfrac{1}{2}(k+l)]\\ &+\bar{O}\{\text{a similar term in } v\}. \end{aligned}$$

$B=0$ in the cases to be considered.

With thirty-two molecules associated with the unit cube, the first reflections observed from the (100) and (110) faces correspond with the fourth order. Third order reflections from planes having indices that are all odd are found in the Laue photographs.

Plane 100:

$$A=\overline{Mg}\{16\cos 2\pi nu+16\cos 2\pi n(u+\tfrac{1}{2})\}+\overline{O}\text{ term.}$$

$$A^{n=2}_{100}=\overline{Mg}\{32\cos 4\pi u\}+\overline{O}\{32\cos 4\pi v\}=0\text{ when }u=\tfrac{1}{4}, v=\tfrac{3}{4}.$$

Plane 110:

$$A=\overline{Mg}\{8\cos 2\pi nu+8+8\cos 2\pi n\ (u+\tfrac{1}{2})+8\cos\pi n\}+\overline{O}\text{ term.}$$

$$A^{n=2}_{110}=\overline{Mg}\{16+\cos 4\pi u\}+\overline{O}\{16+\cos 4\pi v\}.$$

This term also equals zero when $u=\frac{1}{4}$, and $v=\frac{3}{4}$.

Plane 111:

$$A=\overline{Mg}\{8\cos 6\pi nu+24\cos 2\pi nu\}+\overline{O}\ \{\text{a similar term in }v\}.$$

The problem in this case is to determine whether there are values for u and v such that A, for $n=1$ and $n=2$, is practically zero; the intensity of reflection when $n=3$ must be appreciably less than when $n=4$. An approximate solution can be given graphically; a more exact one could, however, only be made if quantitative measurements of scattering were available. The intensity of reflection (or the amplitude) for all values of u and v when n has a particular value can be represented by a three dimensional figure. Certain "iso-u's" of such a figure obtained when $n=1$ are given in figure 3.

The curves enclosing region $n=1$ of figure 4 are obtained by plotting those values of u and v which give a certain small amplitude (as may be determined with the aid of figure 3) on either side of zero (arbitrarily chosen for this representation as +50 and −50). All points lying within this region then will satisfy the experimental requirement that no first order is observable. The regions $n=2$ similarly enclose all values of u and v for which the second order will be negligible. The condition that the amplitude shall be very large in the fourth order is fulfilled within the areas defined by the curves $n=4$. These three conditions are satisfied only in the regions about $u=\frac{1}{4}$ or $\frac{3}{4}$ and $v=\frac{1}{4}$ or $\frac{3}{4}$. It will be observed that when $u=\frac{1}{4}$ and $v=\frac{3}{4}$ the arrangement is identical with that of (c); small deviations from these values could not, however, be detected by the experimental means

available. The arrangement that would result if u and v were both nearly equal to $\frac{1}{4}$ (or $\frac{3}{4}$) is scarcely feasible from a physical standpoint. Thus (j) furnishes a possible arrangement for the atoms in magnesium oxide.

Possible arrangement (k).

This must be treated in a similar fashion to the preceding. Thus the reflection term from the (100) face is

$$A=\overline{Mg}\{8\cos 2\pi nu+8\cos\pi n(1+2u)+8\cos\pi n(\tfrac{1}{2}-2u)$$
$$+8\cos\pi n(\tfrac{1}{2}+2u)\}+\overline{O}\{\text{a similar term in } v\}.$$
$$B=0.$$

When $n=1$, 2 and 3, $A=0$ for all values of u and v.

Plane (110).

$$A=\overline{Mg}\{8+8\cos 4\pi nu+8\cos\pi n+8\cos\pi n(1-4u)\}$$
$$+\overline{O}\{\text{a similar term in } v\}.$$
$$B=0.$$

When $n=1$ or 3, $A=0$.

For $n=2$:

$$A=\overline{Mg}\{16+\cos 8\pi u\}+\overline{O}\{16+16\cos 8\pi v\}.$$

Plane (111).

$$A=\overline{Mg}\{4\cos 6\pi nu+12\cos 2\pi nu+12\sin 2\pi nu-4\sin 6\pi nu\}$$
$$+\overline{O}\{\text{a similar term in } v\}.$$

$B=-A$. For the present qualitative uses it may, therefore, be neglected.

It can be shown by a treatment similar to that applied to (j) that when $u_1=\frac{1}{8}$ and $u_2=\frac{5}{8}$ (for these particular values of u, the thirty-two equivalent positions each reduce to sixteen) and $v=\frac{7}{8}$, there is complete agreement with experiment. Except for the fact that the element whose parameters are represented by u_1 and u_2 will be of two sorts (all of the atoms of the other kind will be alike), this particular arrangement is simply a twice-scale (c) grouping. If, however, u and v had values close to $\frac{1}{8}$ and $\frac{7}{8}$, the differences in the reflections would be so slight as to escape detection. Arrangement (k) thus becomes a possibility.

Grouping (c), the "sodium chloride arrangement" has now been shown to be the only *simple* structure which explains the experimental data, if the arrangement of the atoms in magnesium oxide is really holohedral. The tetartohedral grouping (f), however, can be made to fit

the observations for certain values of its parameters *u* and *v*. Of the various ways having thirty-two molecules in the unit cube, both (*j*) and (*k*) are possible. All three of the structures with variable parameters, however, are in agreement with experiment only when *u* and *v* have such values that the resulting arrangements approximate very closely to the "sodium chloride" grouping.

The nature of the forces between the atoms of magnesium oxide.

Magnesium oxide has just been shown to have probably the same structure as rock salt, (*c*). Some information concerning the possible nature of the binding forces between its atoms in the light of the existing ideas on the forces of chemical combination can be obtained from its analogies with sodium chloride and the other alkali halides.

Two kinds of unions between atoms can be explained by the present knowledge of the structure of atoms.[7] (1) The "electro-negative" atoms of a compound may be able to abstract electrons from the "positive" atoms so that the compound becomes an aggregate of charged atoms held together chiefly by the electrostatic attractions between them. Or (2) if *extremely* electropositive atoms are not involved in the combination, all of the atoms in the compound may strive, without complete success, to acquire electrons in the somewhat inexplicable, but clearly real, attempt to close their clusters of eight outside electrons. Electrons are thus in some way held in common by two atoms—a second sort of bonding which can be called a *valency bonding.*

Partly because of their crystal structures the alkali halides are commonly supposed to be compounds exhibiting the first kind of combination.[8] In sodium chloride each atom, according to arrangement (*c*), is equally distant from six atoms of the other sort and thus there seems to be no connection between what is commonly called the valence, in the chemical sense, of the atoms, and their locations in space.

Similarly the crystal structure of magnesium oxide seems to point to the fact that the oxygen atoms have been able to remove completely the two outside electrons

[7] Ralph W. G. Wyckoff, J. Wash. Acad. Sci., 9, 565, 1919.
[8] J. Stark, Prinzipien der Atomdynamik, III, p. 193.

of magnesium so that the compound is an aggregate of doubly charged oxygen and magnesium "ions."

The writer wishes to express his thanks to C. J. Ksanda for assistance in carrying out parts of this determination.

Summary.

An attempt has been made using Laue photographs and X-ray spectrum measurements to get a *unique* solution for the crystal structure of magnesium oxide. If it possesses holohedral symmetry then the only simple structure which is possible is the "sodium chloride arrangement," (*c*). Certain cases of grouping, showing tetartohedral symmetry and of the more complicated holohedral arrangements, (*j*) and (*k*), each with thirty-two molecules associated with the unit, are in agreement with the existing experiments. These other possibilities, however, differ but slightly from the "sodium chloride arrangement," and can not be positively treated by the experimental facilities now available.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.
October, 1920.

ART. X.—*The Mississippian Formations of the Horton-Windsor District, Nova Scotia;* by WALTER A. BELL.[1]

INTRODUCTION.

The paleontological writings of Sir William Dawson early determined the Horton-Windsor district as the type area for two Mississippian series of formations, the Horton and the Windsor. Later controversies that arose between paleontologists on the one hand, and structural stratigraphers on the other, involved the correlation of the older or Horton formation, a circumstance that lends additional interest to the Mississippian stratigraphy of this district.

Previous work.—Among the previous workers who have written on the geology are such famous names as Sir William Logan, Sir Charles Lyell, and Sir J. W. Dawson. Logan visited the area in 1841, fresh from his geological studies in South Wales, where he had so ably established the true nature of Stigmarian underclays. His discovery in the Horton formation of amphibian footprints (*Hylopus logani* Dawson), in conjunction with the coal-measure appearance of the Horton strata and of the contained flora, led him to consider these beds of Coal Measures age. The gypsiferous or Windsor series was recognized as stratigraphically younger, and fossils gathered at Windsor and submitted to De Verneuil, Keyserling, and Murchison were first regarded as Permian in age. This correlation, however, was doubted by Sir Charles Lyell as long ago as 1843, and he was the first to assign both the Windsor and Horton beds to the lower Carboniferous, a conclusion soon corroborated by Sir William Dawson. For the next fifty years Dawson contributed various papers dealing with the flora, fauna, and stratigraphical relations of these Mississippian rocks. His observations and conclusions are admirably presented in the various editions of his "Acadian Geology."

Later references to the correlation of the Mississippian formations are made by David White, R. Kidston, A. Smith Woodward, L. M. Lambe, H. M. Ami, Charles Schuchert, and J. W. Beede. White (1901) assigned the Horton a Kinderhookian age, with a partial equivalence

[1] Published by permission of the Director of the Geological Survey of Canada.

to the Pocono. The fauna of the Windsor series was considered by both Schuchert (1910) and Beede (1911) to have mainly a Kinderhookian aspect, but certain of the limestones were assigned by Schuchert to the Keokuk or to a somewhat higher horizon.

Scope of the present paper.—The present paper is concerned primarily with conclusions reached after a detailed study of the field relations and of the faunas of the marine Windsor series, begun in 1912. As considerable interest, however, attaches to the earlier Mississippian formations, on account of their terrestrial fluvial origin, a brief description of them is included. These formations, the *Horton* and the *Cheverie,* comprise what has formerly been known as the *Horton series.*

The treatment of the faunas of the Windsor series necessitated the description of more than sixty new species, and the report dealing with these faunas as a whole will be published at a future date by the Geological Survey of Canada. Where new species are mentioned in the present paper, use is made of manuscript names that are subject to revision.

Acknowledgments.—The field work of the present study, which was completed in 1914, was rendered possible by the aid and encouragement extended by the Director and Directing Geologist of the Geological Survey of Canada. The preparation of the manuscript has been done in the laboratories of the Peabody Museum of Yale University, and the writer is particularly indebted to Professor Charles Schuchert of that institution, from whose suggestions the work was originally projected, for constant supervision and inspiration. As Professor Schuchert is personally acquainted with the field, the value of his criticism was greatly enhanced, while the Peabody Museum collection of Windsor fossils gathered by him was generously placed at the writer's disposal.

Thanks are also due to Mr. J. E. Hyde, of Western Reserve University, Ohio, for suggestions made in the field.

Although the work was interrupted by the war, the writer was privileged, when in England, to study the collections of Avonian fossils of the late A. Vaughan, that are preserved in the Sedgwick Museum, Cambridge, and the many courtesies extended him by Professor J. E. Marr, of Cambridge University, are held in grateful remembrance.

Particular pleasure was derived, and benefit received, from direct field observations on the rocks and contained faunas of Lower Carboniferous age in the vicinity of Settle, Yorkshire, and in Westmoreland, under the able guidance of Professor E. J. Garwood, of University College, London, who at the sacrifice of his own pressing affairs cordially exerted himself in the writer's behalf.

Location.—The town of Windsor lies on the estuary of the Avon river some 35 miles in a direct line northwest of Halifax. The district under discussion embraces land with an areal extent of 240 square miles on either side of the estuary and facing north on Minas basin, the southernmost prolongation of the headwaters of the Bay of Fundy. Communications are readily effected with Halifax, Yarmouth, and St. John by means of the Canadian Pacific Railway.

General Geological Relations.

Pre-Mississippian history.—The Mississippian rocks in the district form an undulating lowland with elevations of less than 250 feet, margined on the west and south by an upland of older crystalline rocks that is peneplaned at an elevation of about 500 feet. The sediments of the upland are intensely folded and regionally metamorphosed, with a cleavage at a high angle to the south, and are intruded by an unaltered batholithic mass of coarse, porphyritic, biotite granodiorite. The altered strata are chiefly dark green, pyritized, banded slates, belonging to the gold-bearing or Meguma series of Nova Scotia, generally accepted as of late Proterozoic or Algonkian age, associated south of the Gaspereau valley with a marginal strip of slates and argillites of Niagaran age which have yielded *Dictyonema retiforme* (Hall). The contact between the two slate formations in the Windsor district is the result of pre-Mississippian faulting, with upthrow on the south, but farther to the west in the Kentville district, a larger mass of Silurian rock is said to follow the Precambrian slates without angular discordance.

The orogenic disturbance, with granitic intrusion as an end phase, that produced the folding and regional metamorphism of these rocks, affected elsewhere sediments of Oriskany age and represents the outstanding historic event of the whole region. It was named many years ago

by H. S. Williams the *Acadian orogeny*. Although this disturbance must have resulted in a constructional topography of high relief, the basal Mississippian contact in the Windsor district indicates that these mountains were worn down to peneplanation prior to early Mississippian times. Not only do the basal Horton sediments of Kinderhookian age truncate at a flat angle both slates and granite, but there is evidence of pre-Mississippian weathering in the oxidized nature of the slates and in the disintegrated condition of the granite for several feet beneath the contact.

Structure and physiography.—The slopes that connect the lowland with the upland are everywhere steep. In the western margin of the district there is a rise of several hundred feet within half a mile, while the ascent in the south is still more abrupt. The latter was determined to be the erosional expression of a fault, here named the *Butler Hill fault,* that has a stratigraphic throw in the district in the neighborhood of 2,000 feet. As a result, hard crystalline rocks on the south are brought up against very soft rocks of the Windsor series of upper Mississippian age. This fault that margins the Windsor lowland in the south was traced for several miles northeastwards beyond the confines of the district. The border of upland and lowland in the west does not show a response to faulting, but is a sinuous one determined by post-Mississippian folding that has affected the crystalline floor as well. The present main streams, e. g., Gaspereau river, Halfway river, Mill branch and West branch, all of which are tributaries of the Avon river, are located in synclinal valleys that are underlain by Mississippian rocks, whilst the divides between these streams are in the nature of projecting "capes" from the upland developed on the older crystalline rocks. This relation has given rise to the erroneous impression current in the literature that the margin of lowland and upland is an inheritance from an old Carboniferous shore-line.

The lowland of the Windsor district is underlain by rocks of so soft a nature and is so maturely dissected by the Avon river and its tributaries that it is not known to what extent its formation is due to marine planation on the one hand or to subaerial denudation on the other. At present, the lower reaches of the rivers are submerged and an estuarine cycle is in process. Tides of 20-30 feet mean range have resulted, and that these are effective

agents of erosion is evident from the maintenance and rapid undercutting of cliffs. It is only in favored localities, such as over alluvial flats bordering the upper limits

Fig. 1. Geological map of Horton-Windsor district. Scale 4 miles = 1 inch.

of tidal action, that extensive aggradation has taken place, with the formation of estuarine plains such as that of Grand Pré in the north of the district, the historic ground of the early French settlers.

The basal Mississippian sediments belonging to the Horton formation that flank the upland in the west have suffered practically no folding beyond the broad flexures already noted. To the northeast, however, where higher and better laminated strata of the Horton outcrop along Minas basin, they are affected by numerous minor asymmetrical folds and corrugations which have their axial planes inclined to the northwest.

The very soft strata of the Windsor series are characterized by numerous small flexures and are broken by many faults that are mainly thrust slips consequent upon stretching of the limbs of the folds. In general, these slip planes dip steeply southwards, and where closely spaced, the strata have isoclinal dips and are locally overturned. Such a complex structure, combined with the presence of thick zones of gypsum and very poor exposures, renders the interpretation of the stratigraphic sequence exceedingly difficult. The stratigraphic throws along the slips vary from several tens to several hundreds of feet.

The northward dip of the axial planes of the folds in the northern part of the district is believed to be due to the influence of the resistant crystalline mass of the Cobequids north of Minas basin, which bulwark is expressed topographically at the present time by the narrow upland known as the Cobequid mountains.

Post-Mississippian history.—The Windsor series of late Mississippian age is the last sedimentary record of marine transgression within the Maritime Provinces prior to the Champlain epoch. The folding that affected the Mississippian rocks took place before the close of mid-Pennsylvanian (Westphalian) time, with the balance of evidence in favor of an early Westphalian orogeny. Rocks of Pennsylvanian age have been entirely removed by erosion from this district, with the exception of a very small patch of sandstone that may represent a faulted inlier. The district was once more reduced to peneplanation before the deposition of the semi-arid terrestrial deposits of Newark age (early upper Triassic).

Stratigraphy and Correlation.

Mississippian sequence.—In descending order the succession of Mississippian formations is as follows:

Tennesseean (Chesterian equivalent).
  Windsor series (marine).................. 1100′+
  Disconformity.
Tennesseean (Meramecian equivalent).
  Cheverie formation (terrestrial)........... 600-800′ max.
    Characterized by *Estheria dawsoni* Jones and *Leaia salteriana* (Jones & Kirkby).
  Disconformity.
Waverlian (Kinderhookian equivalent).
  Horton formation (terrestrial)......... 2800-3400′± max.
    Characterized by *Aneimites acadicus* Dawson and *Lepidodendron corrugatum* Dawson.
  Unconformity.
Silurian and Precambrian slates and Devonian granodiorite.

Horton Formation.

Description.—Broadly the Horton may be divided into a basal feldspathic arenaceous member (650-2,000 feet thick) which carries rare faunal remains, and an upper argillo-arenaceous shale member (300-1,400 feet thick) with abundant Ostracoda and fish scales at various horizons. The feldspathic sediments at the base flank the bordering upland with a present mean dip of the warped contact surface of about 12°. The composition of the immediate contact beds is in direct relation to that of the underlying rock. Where the latter is slate, for example, the lowermost Horton bed of several feet thickness is a compost or agglomerate consisting of angular to subrounded fragments of the underlying rock embedded in a paste of the same material with but occasional pebbles from more distant localities. Above this thin sheet of basal agglomerate the stream-deposited feldspathic grits and arenaceous shales so characteristic of the Horton were laid down. The grits, in which the grain of the matrix ranges from 7 mm. downwards, consist of transparent angular quartz, rounded flakes of dark slate, kaolinite and muscovite. Conglomeratic basal beds carry in addition pebbles of vein quartz, quartzite, or slate. The coarser beds are heavily cross-bedded, whilst the slates are typically marked by ripples predominantly of the current type.

The peculiarity of the succeeding beds lies in the presence of frequent zones of laminated, siliceous, and argillaceous shales, with which are commonly associated ironstone concretions, abundant spheroidal calcareous concretions, and occasional thin argillaceous limestones

with a cone-in-cone structure. Certain beds in these zones are abundantly rich in leperditioid and beyrichioid ostracods, *Spirorbis,* and the scattered scales and dermal bones of palæoniscid fishes. The ostracod beds are of a more argillaceous character, and are more restricted in their vertical distribution, being mainly confined to the middle part of the Horton.

The higher beds of the upper Horton comprise a thick accumulation of finely siliceous shales associated with thick interzones of non-laminated, or but poorly laminated, argillo-arenaceous deposits that break with a characteristic hackly fracture, and that weather frequently to variegated light greenish and buff-yellow colors. An extraordinary feature presented by these beds on their exposed bedding surfaces is a polygonal system of cracking that might readily be mistaken for true sun-cracking. Careful inspection, however, reveals the presence of carbonaceous traces of a dichotomously branching system of rootlets, and not uncommon association with casts of upright tree stems, denoting clearly that they are fossil soils. It is these early soil zones that lend to the deposit its greatest interest. Although they may be observed in their best development in the upper Horton (they are particularly well displayed along the Cambridge shore), their occurrence is widespread both vertically and laterally, and they are eminently characteristic of the whole deposit. In several hundred feet of strata in the upper Horton, fifty-six well marked soil zones were noted, of which seven had associated with them abundant upright tree stems. Additional soils and upright stems were present in the ostracod-bearing division below. The abundance of these upright stems in the horizons in which they occur is evident from the fact that ninety-six were counted in a plot 150 × 15 feet. The stems are small, rarely exceeding 11 inches in diameter, and usually not more than a foot of the height can be traced. As regards the rootlets in the soil zones, their casts and imprints are indistinguishable from the rootlets of *Stigmaria ficoides* of the Coal Measures. It is a striking fact, however, that no creeping "rhizomes" comparable to *Stigmaria* were found anywhere in the Horton formation, while several upright stems had directly attached to them rootlet-like appendages that branched dichotomously. The absence in the Horton of true *Sigillaria* and the association

of these stems with the ubiquitous drift of *Lepidodendron corrugatum* Dawson suggest the strong probability that the upright stems belong to this species. An absence of horizontally spreading *Stigmaria* is in agreement with the arenaceous character of the Horton soils and absence of carbonaceous seams, which point rather to good drainage and lack of permanent swampy conditions before burial.

Throughout the formation, broken plant material is common. Larger recognizable fragments are almost exclusively cortical imprints of *Lepidodendron corrugatum* Dawson or of the broken foliage and rachises of the pteridosperms *Aneimites acadicus* Dawson, two species represented by close allies in the American Pocono. In the upper beds, large megaspores (*Spongites glaber* Dawson) 1-2 mm. in diameter are very abundant at certain horizons. A single specimen of *Asterocalamites* cf. *scrobiculatus* Schlotheim was found as a stray fragment, presumably from the upper Horton.

In the restricted fauna the following ostracods are most characteristic: *Jonesina nova-scotica* (Jones), a beyrichioid allied to *Beyrichia colliculus* Eichwald; *Kirkbyina acadica* n. sp., a larger and more quadrate form than *K. reticosa* (Jones & Kirkby); *K.* cf. *scotoburdigalensis* (Jones & Kirkby); *Carbonia* cf. *pungens* Jones & Kirkby.

The fish scales of most common occurrence are assigned to the genus *Elonichthys,* differing from *E. brownii* (Jackson) from the Albert series of New Brunswick, in the possession of nonserrate margins. Maxillæ of *Rhadinichthys* are not uncommon. Rarer remains are jaws and teeth of *Strepsodus,* and selachian spines of the genera *Stethacanthus* and *Ctenacanthus.*

Depositional environment.—Marine conditions are excluded as inconsistent with a widespread extension of rootlets and plant stems *in situ,* an exclusion corroborated by the textural features of the deposits. General uniformity of deposition, carbon content, absence or rarity of desiccation cracking, ferrous condition of the iron content, etc., testify to pluvial conditions. Among the possible terrestrial deposits, a fluviatile accumulation under humid climatic conditions is postulated as most consistent with all the facts. The laminated ostracod-bearing shales may represent temporary lacustrine deposits on the river plain. While the presence of the beyrichioid

Jonesina seems unfavorable to a fluvial or lacustrine origin of the particular sediments in which it is found, the remaining evidence is so overwhelmingly in favor of a terrestrial deposition that it is believed a fresh-water adaptation of this genus must be accepted.

The accumulation and preservation of several thousand feet of terrestrial sediments characterized by abundant soil levels calls for a differential subsidence of the basin of deposition. Two convergent lines of evidence fix the source of material in nearby upland masses lying in a general southwesterly direction. Primarily, the composition of the sediments points unequivocally to the belt of Devonian granites and Precambrian slates and arkosic quartzites of the Meguma series, which outcrop at present for 120 miles to the southwest before they sink beneath the Atlantic. The second line of evidence is presented by the alignment of the current ripples. By plotting the results of many observations, the mean trends indicate the dominance of currents from the southwest.

Correlation.—The plant evidence has been effectively summarized by David White, who correlates the Horton with part of the Pocono, assigning to it a Kinderhookian age. The fish genera *Elonichthys* and *Rhadinichthys* establish the Carboniferous age of the deposits, whilst the ostracods have their nearest allies in the Lower Carboniferous of Europe.

Upper contact.—Although the Cheverie formation succeeds the Horton without *angular* discordance, a marked disconformity is inferred. There is a distinct climatic break and the thick clastic beds at the base of the Cheverie suggest also a marked uplift of the headwater region that was undergoing erosion. Moreover, local mountain-making movements at this time are indicated by heavy conglomerates of Cheverie age in the Moncton area, New Brunswick.

Cheverie Formation.

Description.—The Cheverie formation attains a maximum thickness in the district of from 600 to 800 feet. The basal 300 feet is dominantly made up of gray arkose grits with a subordinate amount of chocolate argillo-arenaceous shale and occasional beds of micaceo-arenaceous shale of a greenish black color. The arkose consists of angular fragments of transparent quartz up to 15 mm. diameter, with angular fragments of feldspar of

like dimension. Biotite mica, little altered, is commonly present in flakes up to 3 mm., and may be in excess of muscovite. The binding material is largely kaolinite which renders the arkose friable. Slate particles are of minor importance. The upper strata of the formation are dominantly purple-red argillo-arenaceous shale with occasional thin zones of greenish micaceous shale or slate-grey argillaceous *Estheria*-bearing shales. These dark shales yield likewise a few plant remains and rare specimens of *Leaia*. The red shales are commonly non-laminated, weather in a hackly manner, and frequently contain small irregular concretionary calcareous nodules.

The phenomena of current ripples and cross-bedding are as widespread in the Cheverie as in the Horton. Channeling of the grit beds into underlying shales is a marked feature, and frequently large torn angular remnants of shale are included in the arkose. Sun-cracking has been observed in several instances, although the exposures are unsuitable for observations of this nature. Striking features of this cracking are the sandy nature of the beds in which it occurs, the relatively great width of the fissures, the coarse infilling, and the fact that the cracked beds have traces of rootlets *in situ* and represent old soils.

Biologically the features presented are a repetition of those of the Horton formation, but are here in a more restricted development consequent to a more advanced degree of subaerial exposure. Rootlets *in situ* are common throughout all the argillo-arenaceous non-laminated shales, notwithstanding the fact that the strata are now dominantly red and practically devoid of other organic remains. The traces of rootlets are, however, less frequent than in the Horton formation, and are most commonly represented by slight color distinctions, with traces of carbon of rare occurrence. At times the oxidation of the carbon took place at the expense of oxygen combined with the iron, giving rise to grey contact zones. Upright stems were observed in one instance in a purple-red shale in which thirty-three stems were counted in a plot 29 × 146 feet. The drift flora is practically restricted to occasional thin seams of dark shale, but the flora so far gathered is of too fragmentary a nature for reliable specific identification. It appears to be more varied than that of the Horton, with sphenopterid types dominant.

In addition to *Estheria dawsoni* Jones, which is common, there is a *Leaia* of rarer occurrence, a very significant fact, as *Leaia* elsewhere in America is eminently characteristic of the Pennsylvanian.

Depositional environment.—The same features that denoted a fluvial environment in the case of the Horton are here repeated, some of them in accentuated forms. Thus channeling, sun-cracking, fresh feldspars, little altered biotite, oxidized iron content, etc., are dominant properties of the Cheverie that give a unity to the deposit and differentiate the formation as a whole from the underlying one. As the material itself has been derived from the same general land mass that supplied the Horton detritus, it is reasonable to attribute climatic influence as the main control of the chemical and textural features of the sediments. Tumultuous current action at recurrent intervals in the basal arkose mass, in conjunction with the presence of soil beds at like intervals, would call for rhythmic pronounced accessions of water flow and a sufficiently high level of the ground water in the river flats during the intervals to favor a vegetable growth. From a study of present-day climates, it would seem necessary to postulate a warm temperate semi-arid type to fulfill all the requirements. That extreme arid conditions were wanting is evidenced by the absence of pebbles. The presence of nodules of reddish calcium carbonate in the red soil beds of the upper part of the formation suggests homology with the "kankar" in the alluvium of the Indo-Gangetic plain.

Correlation.—The stratigraphical position of the Cheverie formation between the Horton below of Kinderhookian age and the Windsor series above of Chesterian age does not closely define its position in the Mississippian. It is the addition of an eremopterid flora and the distinct climatic break that have led to the inclusion of the Cheverie in the lower Tennesseean rather than in the Osagian. The break between the two terrestrial formations, the Horton and the Cheverie, is believed to be greater than that between the terrestrial Cheverie and the marine Windsor.

Windsor Series.

Description.—The Windsor series comprises a well defined unit of marine deposits laid down under peculiar

environmental conditions. There are three and probably four zones of calcium sulphate deposits (gypsum and anhydrite), averaging roughly 50 feet each, separated by varying amounts of brick-red argillaceous shale and fossiliferous limestone with subordinate thin dolomitic sandy shales, oölites, and calcareous algal bands. In amount, the gypsum and anhydrite may make up some 10 per cent of the total estimated thickness of 1100 feet, with red shale 50 per cent and calcareous beds 40 per cent. Estimates of the thicknesses of this series, however, must be considered as but very rough approximations, owing to the poorness and isolated nature of the exposures, and to the presence of numerous fault slips of which mention has been made. The sequence of faunal zones presented here is necessarily dependent on the writer's interpretation of the structure, and is not advanced as an established fact. Better and less broken sections may be found elsewhere in the province that will necessitate a considerable revision of the following succession. The sequence as given below is radically different from that presented by Hartt (1867) and in Dawson's "Acadian Geology."

Upper Windsor or *Martinia* zone. Characterized by *Martinia opertacosta* n. sp.
 Subzone D. Characterized by *Caninia dawsoni* (Lambe) 460′±
 Subzone C. Characterized by *Dibunophyllum lambei* n. sp. .... 270′
Lower Windsor or *Composita* zone. Characterized by *Composita dawsoni* (Hall & Clarke).
 Subzone B. Characterized by *Diodoceras avonense* (Dawson) .... 265′±
 Subzone A. Basal limestone and *Sanguinolites* phase.. 95′±

The Windsor beds disconformably overlie the Cheverie formation. The basal member is a fine calcareous quartzite whose upper surface is locally marked by interior molds of the valves of a *Sanguinolites*. Commonly both valves are attached and flatly opened. A thin conglomeratic development with limestone pebbles, probably of an intraformational character, follows the basal arenaceous bed, and is succeeded by platy brecciated limestone which carries calcite vugs and occasional nodules of pyrolusite and manganite of secondary origin. This manganiferous mineralization is of such widespread occurrence at this horizon that it is probable that the manganese content was originally disseminated in the limestone at the time

of deposition. The subzone terminates with a thick band of anhydrite and gypsum.

Subzone B is characterized by the presence of two limestones that are extremely fossiliferous, and as they outcrop in the vicinity of the town of Windsor, they afford a rich collecting ground. The lower or *Maxner limestone* is about 80 feet in thickness, the upper or *Miller limestone* about 35 feet, the two being separated by a second band of gypsum. The fauna is common to the two limestones, but the association is somewhat different. The Maxner limestone is characterized particularly by the abundance of *Diodoceras avonense* in its upper portion and by the great profusion of individuals of species of *Dielasma* and *Composita* in which the brachidia are excellently preserved within the hollow interiors. The Miller limestone is characterized by an abundance of Aviculopectens, bryozoans, and productids.

Subzone C is best exposed on the Avon estuary at Windsor in the neighborhood of the bridges. The section, however, is broken by a number of important faults. The lower part of the subzone has frequent oölitic, algal, and sandy dolomitic beds that are sparingly fossiliferous, but in the upper part some 20 feet of platy blue limestone furnishes abundant *Martinia* and *Productus.*

Subzone D has a thick gypsum member at its base, in which are a number of thin calcareous seams crowded with ostracods and with the foraminifer *Nodosinella.* The upper beds are best exposed at the mouth of Kennetcook river, where 100 feet of thinly bedded blue-grey limestones carry a fauna which is more normally marine than any which preceded it. Cup corals become abundant here for the first time, there is a greater variety of brachiopods, and the molluscs are mainly confined to the Bellerophontidæ.

The following generalized lithological section illustrates the rhythmic recurrence of mud deposition with chemical and organic deposits:

D. Kennetcook limestone.......................... 100′+
  Gypsum and anhydrite with *Nodosinella* bands.
  Red shale, etc.
C. Avon River limestone .... 45′+
  Gypsum? and red shale.
  Dolomitic and calcareous shales and sandstones, oölites, algal and *Modiola* bands.
B_2. Miller limestone .... 35′

Gypsum, anhydrite, and red shale.
B_1. Maxner limestone .... 80′
Gypsum, anhydrite, and red shale.
A. Basal limestone, conglomerate, and quartzite.

Environmental factors.—As interbedded chemical deposits and red argillaceous shales form so prominent a feature throughout the Windsor series, it is evident that the biotic conditions were decidedly abnormal, a fundamental fact that must be borne in mind in comparative studies with other faunas. The most significant factors of the Windsor seas were shallow waters, probable high temperatures, and varying salinities, culminating at intervals in conditions intolerable to a bottom life. These unfavorable conditions were not confined to local pools, but were of widespread extent in the Windsor basin.

The shallow-water conditions that prevailed were doubtless maintained by progressive subsidence in a manner analogous to the previous differential movements that controlled the terrestrial deposition in the basin. A "barrier" of some sort certainly existed against free communication with the outer sea, and it was more probably a tectonic upwarp due to the same differential movements than a depositional sand or gravel bar or a current barrier established by differential salinites or by controlling winds alone. The Windsor sea, moreover, was of a geosynclinal Paleozoic type and not a shelf sea in the nature of the present Rann of Cutch. There is, furthermore, no evidence at hand for complete isolation, and the "breaks" in the sequence are in the nature of diastems or minor disconformities. Stages of extreme shallowness took place in the middle of the epoch, as attested by dolomitic sands, algal bands, oölites, *Modiola* bands, etc., which beds are characterized by peculiarly restricted faunules, whilst the nearest approach to normal marine conditions was reached in the late life of the sea.

Desiccation rarely proceeded beyond the precipitation of gypsum or anhydrite, but this alone would demand, since there were no marked volume contractions, a surface inflow from the outer sea of four to nine times the volume of water in the basin under conditions in which the evaporation would approximately balance the accessions.

The times of gypsum or anhydrite deposition were not the only ones that prohibited the establishment of an

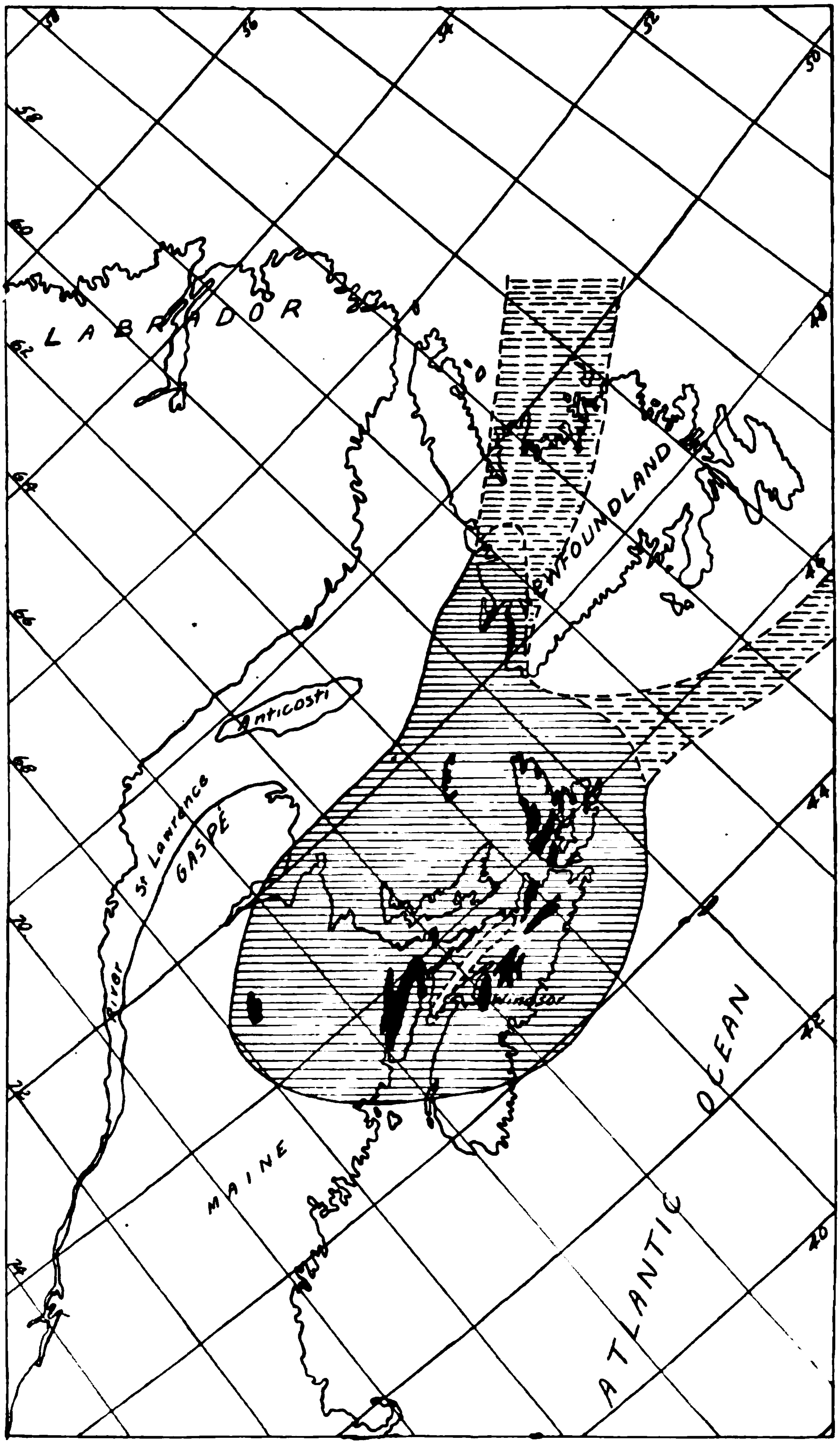


FIG. 2. Hypothetical extension of Sea in Lower Windsor time.

indigenous fauna, as red shales make up nearly one half of the total mass of the sediments, and so far as known are barren of fossils. In this case the extreme muddiness of the waters, combined with probable high temperatures (warm seas at this time are indicated by abundant reef corals in western Europe), was equally deleterious to animal life.

Faunal selection.—Unfavorable biotic conditions would affect various organisms differentially. They would be particularly prohibitory to the establishment of certain groups of greater sensibility, such as the corals, and it is not surprising that colonial corals have not been found in the Windsor deposits and that cup corals are very meagrely represented and gain only a temporary footing in the more normal marine waters of late Windsor time. An analysis of the Windsor fauna shows that of 104 species belonging to 63 genera, 48 species representing 22 genera are brachiopods, and 36 species representing 25 genera are molluscs. The fauna, therefore, as determined by the physical environment is essentially a molluscan-brachiopod one.

The composition of a faunal assemblage, however, is dependent not only on the direct environmental factor but on the available routes of migration. While the Windsor faunas show very little in common with the Mississippian faunas of interior America, there are clear affinities with the faunas that inhabited the seas of western Europe at this time. Accordingly, absentees in the Windsor faunas may likewise be absent or illy represented in the Avonian (Lower Carboniferous) faunas of the North Atlantic province with which direct migratory relations were established. This factor alone might account for the meagre representation of crinoids as mere stem fragments, for the absence of blastoids, and of such specialized bryozoans as *Archimedes* and *Lyropora.*

Correlation with the Viséen.—In correlating the Windsor faunas it is natural to turn in the first place to their nearest allies, the Lower Carboniferous faunas of western Europe. To the Belgian geologists, who were among the first to illustrate these faunas, we are indebted for the recognition of two major faunal divisions, the Tournaisien below and the Viséen above, corresponding approximately to the Waverlian and Tennesseean, respectively, of the American sequence. In recent years, British paleontologists, led and inspired by the admirable studies of

A. Vaughan, have worked out in great detail the faunal sequence in their Lower Carboniferous or Avonian rocks (Vaughan 1905, 1915; Garwood 1912; Dixon 1911). While opinions differ as to the placement of the division line between the Tournaisien and Viséen, there is general agreement as to the faunal successions throughout the British and Belgian field. The northern part of the British Isles, however, is characterized by an arenaceous or abnormally marine facies and much remains yet to be done on the correlation of the beds that make up the Calciferous and Limestone series of Scotland. The latter facies is rich in the Mollusca as contrasted to the coral-brachiopod faunas of the calcareous or "Mountain limestone" facies.

In comparing the Windsor faunas with the Avonian faunas of England, the affinities are seen to lie with the upper Avonian or Viséen rather than with the lower Avonian or Tournaisien. The presence in the lower Windsor zone of abundant *Composita* of the "*ficoides*" form, associated with *Productus* of the type of *cora* and *corrugato-hemisphericus,* is in striking conformity with the faunal assemblage in the middle Viséen (S_2) of the Avonian sequence. Of the Mollusca, which dominate the lowest fauna at Windsor, there are species identical with or closely allied to species from the *Lower Limestone* series of Scotland, or from the Redesdale limestone of Northumberland, both of which are well up in the Viséen. Thus, *Sanguinolites parvus* n. sp. is probably synonymous with *S. striatogranulatus* Hinde from the Redesdale; specimens of *S. tricostatus* identical with Portlock's species from the Redesdale limestone occur at Windsor; *Lithodomus lingualiformis* n. sp. is very close to *L. lingualis* Phillips from the Viséen of Castleton; *Murchisonia compacta* is identical with *M. compacta* Donald from the *Upper Limestone* series of Dalry, Scotland.

The upper or *Martinia* zone at Windsor is characterized by the entrance of a clisiophyllid cup coral belonging to the genus *Dibunophyllum,* which is an early form of the type of *Dibunophyllum* aff. ψ Vaughan, as well as by the abundant occurrence of *Martinia* of the *M. glabra* form type. Both of these genera are characteristic Viséen genera, and *Dibunophyllum* especially has been found a good index to the upper Viséen of England. The following species from the upper limestone of Windsor afford additional links on which a correlation of the

Windsor *Martinia* zone with the lower part of the *Dibunophyllum* zone is based.

Zaphrentis minas Dawson is distinctly of the type of *Z. enniskilleni* Edwards & Haime. In England this group ranges from the upper Tournaisien to the upper *Dibunophyllum* zone, but is especially characteristic of the Viséen.

Lophophyllum avonense n. sp. In Europe, *Lophophyllum* attains its maximum in strata of upper Viséen age, or in beds immediately succeeding, although it is found sparingly in the upper portion of the Tournaisien.

Tabulipora acadica n. sp. is a dendroid trepostomatous bryozoan that is very abundant near the base of the Kennetcook limestone. It is characterized by the thinness of the peripheral zooecial walls, which nevertheless show a distinct moniliform structure. *Tabulipora* is essentially a Viséen genus, and *T. tenuimuralis* Lee from the Eelwell limestone, Lowick ($= D_2$?), agrees with the Windsor species in the tenuity of its walls.

Avonia spinifercardinata n. sp. is very close to *Productus longispinus* Sowerby.

Chonetes politus, the only *Chonetes* yet gathered from the Windsor beds, is identical in all respects with McCoy's species from the base of the *Lower Limestone* series of Scotland.

Spirifer bisulcatiformis n. sp. is indistinguishable from *S. bisulcatus* var. *oystermouthensis* Vaughan from D_2-D_3 Gower (Dixon 1911). The *bisulcatus* type of *Spirifer* occurs rarely in the middle Avonian but has its maximum in the upper Viséen.

Martinia opertacosta n. sp. This species lacks dental plates and has the shell structure of a true *Martinia.*

Phillipsia howi Billings. This species has been correlated by Vogdes with *P. meramecensis* Shumard, on the evidence of pygidia only. Several cranidia, however, found by the writer, one of which is still attached in a crushed rolled specimen, determine the Windsor species to belong to the gens of *P. eichwaldi* Fischer, which occurs in the *Lower* and *Upper Limestones* of Scotland and at Bolland, Yorkshire.

Allorisma sulcatiforme n. sp. is perhaps identical with *A. sulcatum* Fleming from the Redesdale limestone and the *Limestone* series of Scotland.

Aviculopecten dissimilis Fleming, from the *Limestone* series of Scotland and from the Four Laws limestone of

Northumberland, occurs in the upper Limestone of Windsor.

Correlation with the American Tennesseean.—The dissimilarity of the Windsor faunas to those of like age in the Mississippian basins of America was early noted by Dawson and subsequently confirmed by Schuchert and Beede. Dawson, moreover, clearly perceived their European alliances and attributed their isolation from the western faunas to the existence of an Appalachian mountain barrier. The difficulties of correlating a fauna which is dominantly a molluscan one are well exemplified by the fact that Beede, who described faunas of this age from the Magdalen islands, was impressed with the Devonian or early Mississippian aspect of some of the pelecypods, whilst earlier paleontologists, e. g., Meek and Newberry, emphasized their Permian appearance. In the present correlation, reliance is placed rather on the occurrence of several brachiopods and bryozoans that either hold a limited range in, or make a definite entry into, the Mississippi Valley basin.

In the upper Windsor zone, several species belonging to *Martinia, Composita,* and *Productus* present evidence of an age synchronous with some part of the Chesterian group. *Martinia opertacosta* n. sp. is a form closely allied to *M. contracta* (Meek & Worthen). *Composita obligata* n. sp., common in, and characteristic of, the upper Windsor limestones, is so close to *C. subquadrata* (Hall), a characteristic Chesterian species, that it may well be specifically identical. *Productus* (*Avonia*) *multiplexiseptum* n. sp. is likewise probably specifically equivalent to *P. parvus* (Meek & Worthen) from the Ste. Genevieve and Chesterian groups. Thus there is direct evidence of Chesterian affinities. Indirectly, the same conclusion is reached, as the fauna of the upper zone at Windsor correlates with that of a lower *Dibunophyllum* age in the European time-scale.

The lower fauna at Windsor, while it likewise indicates Chesterian affinities, is seemingly an earlier expression and may be in part equivalent to the Ste. Genevieve. The Compositas, which are extraordinarily abundant in individual representation, belong mainly to two species of European stock, and while the productids of the *cora* and *semireticulatus* types are too plastic for correlation purposes, they likewise are closer to the European species. urrence in the fauna of a true *Diaphragmus* is the

most suggestive character, as this genus makes its first appearance in the Ste. Genevieve and the *D. montesanæ* Ulrich (1917) is close to the Windsor *D. tenuicostiformis* Beede. The bryozoans afford additional evidence in their Chesterian affinities. Thus *Batostomella exilis* (Dawson) and *B.* cf. *abrupta* Ulrich are two species, associated in abundance in the Miller limestone, that are almost indistinguishable in their external and internal characters from *B. spinulosa* and *B. abrupta* Ulrich. The fenestellid of most common occurrence, *Fenestella lyelli* Dawson, reveals close analogies with *F. elevatipora* Ulrich, while *Septopora parva* n. sp. has the small delicate zooarium of *S. delicatula* Ulrich associated with a like arrangement of accessory pores on the reverse surface. It is concluded that the Chesterian affinities of this lower Windsor fauna are too strong to assign to it as low a position as the St. Louis, and it is provisionally referred to the Ste. Genevieve.

Climatic correlation.—The semi-aridity characteristic of Tennesseean time in Nova Scotia during the deposition of the Cheverie and Windsor formations is in agreement with conditions of semi-aridity in Pennsylvania during Mauch Chunk time and in Michigan during the deposition of the Michigan series.

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Art. XI.—*Relation of Subjacent Igneous Invasion to Regional Metamorphism;* by Joseph Barrell.

(Continued from page 19)

PART II. METAMORPHIC AND METASOMATIC RELATIONS OF OROGENIC BATHOLITHS.

Heating and Crystallizing Effects of Magmas.

If subjacent magmas are a primary factor for the production of regional metamorphism, they must act through their heat and emanations. Their magmas, on their initial rise in undifferentiated form, appear to possess a heat of not less than 1200° C., but the final crystallization of granite takes place at temperatures below 870° C. and above 575° C. This degree of cooling must occupy a long time, and as the bodies of molten rock are vast, there is sufficient heat passing out to raise the cover rocks to a highly abnormal temperature. The curves of temperature and their relation to time, as based on the laws of conduction, can not give definite information, since the heat transfer into the cover rocks is doubtless largely by gaseous transfer, in advance of conduction.[14] Gaseous transfer could, if sufficiently rapid and prolonged, heat the entire cover to that thermal curve dependent upon the adiabatic expansion and reactions of the gases. Differentiation, by which granites are derived as a final stage from antecedent more basic magmas, implies a low viscosity in all of the earlier stages of magmatic rise. It seems probable that there is saturation with gas under pressures of 1000 atmospheres or more, and at temperatures of the initial intrusions. The great portion of the cover can then be heated up to temperatures at which garnet, staurolite, sillimanite, feldspar, muscovite, and hornblende can crystallize. The temperature conditions for anamorphism may be brought comparatively near to the surface. Above this will be a zone of hydrothermal alteration.

Chemical or Metasomatic Effects of Emanations.

The study of metamorphic formations shows that except for the elimination of volatile constituents the bulk

[14] [The mechanism of this advance transfer of gaseous solutions has been outlined by C. N. Fenner, Jour. Geology, 22, 594 and 694, 1914.]

of the rocks retain rather closely their original composition. Upon entering a rock formation, the passing emanations seem to establish rather quickly a chemical equilibrium, and thence to carry forward a heating and crystallizing effect. But although this is true in a large way, it is far from being a universal principle. There is more or less transfer of magmatic material into the wall rocks, and reaction with them, with resulting metasomatism: amphibolite, garnet, and albite, as well as other minerals, may be largely developed as a result. The acidic magmas are much more important in this respect than the basic, but wide individual variation is to be observed.

It is thought that the emanations from the same magma at different stages are of highly different character. The first gases are probably eliminated by supersaturation before any crystallization. They include especially the volatile constituents, chlorine, fluorine, boron, and water, but most of the non-volatile oxides remain behind in mutual solution. Another stage seems to carry off chiefly silica and iron, and a following stage is rich in water-vapor holding in solution the quartz and feldspar which make the pegmatites.

The metasomatic zone is to be expected, and is in fact found, on the inner side of the metamorphic zone, developing in sequence following the first or metamorphic recrystallization. It is apt to be very irregular in boundary, following the zones of easiest passage through the rocks. In very deep-seated masses, as in the Grenville limestones involved in Laurentian granite, the result is very much more pervasive than in more shallow zones. Surrounding plateau batholiths (those intruded without relation to orogenic pressures and rock mashing), limestones offer the most favorable channels for the extension of the metasomatic zone, since they are subject to volume changes, shattering, and ready chemical alteration. Where non-uniform mountain-making pressures have operated, however, giving rise to foliated structures,[15] the schists become the most favorable channels for conducting away the solutions and an intimate interfoliation of country rock and magma may result, known

[15] [See John Johnston and Paul Niggli, The general principles underlying metamorphic processes, Jour. Geology, 21, 599, 1913. This paper calls attention to the fact that non-uniform compression has a much more important metamorphic effect than uniform pressure.]

as the *lit-par-lit* structure. (For further discussion, see Part III.)

Prevention of Deep Penetration of Meteoric Waters.

In the discussion of the anamorphism of the rocks of northwestern Connecticut, it developed that there is evidence, in the addition of tourmaline and silicates, that rising waters were active, but no conclusive evidence has been presented that the waters were of magmatic origin. The relative place which meteoric and magmatic waters hold in carrying forward the work of metamorphism is a long debated question. In contact metamorphism, it is now held by the majority of workers that magmatic waters are the controlling factor, but meteoric waters of vadose or connate origin are still commonly regarded as the agents active in regional metamorphism.

It was formerly an accepted part of geologic theory that the mechanism of volcanoes involved a free downward percolation of sea waters. The Daubrée experiment, showing the capillary passage of water through a porous sandstone against pressure and into a steam-filled chamber, was thought to support the view. The diffusion of water under great pressure through the intermolecular pores of glass and metals has also been held to be supporting evidence.

The conditions of the Daubrée experiment do not apply, however, to the vast thickness of non-porous crystalline rocks. The diffusion of water through glass and metals is effective only under an enormously steep pressure-gradient which has no direct relation to the high pressures but low pressure-gradient of the earth's interior. Igneous rocks come from depths below the zone of sedimentary rocks and the emanations show compositional characters in the possession of abundant carbon gases, fluorine, and boron, which indicate a lack of relationship to downward percolations. Lastly, and perhaps most conclusively, mining operations show the zone of meteoric waters to be relatively shallow, confined in definite zones to porous or fissured rocks, and the rocks below to be dry. Soluble constituents such as salt and gypsum, if in rocks well below base-level, are permanently preserved from solution and show the absence of pervasive circulating waters.

These reasons have caused the majority of geologists to look upon gases or fluids which carry forward the

work of contact metamorphism and of primary ore deposition as juvenile in origin—making their way for the first time toward the surface of the earth.

The waters which serve as the agents for the recrystallization taking place in the anamorphism of sedimentary formations must be, however, in part original occlusions; yet it is doubtful if they alone are competent to serve as agents for the development of schists and gneisses. The changes from mud to shale, from shale to slate and thence to schist show a progressive elimination of the water both of composition and occlusion. A later coarse-grained crystallization, especially if accompanied by fluorinization, suggests the added agency of magmatic waters.

But waters arising from magmas bring with them the hydrostatic pressure of the greater depths, diminished by their own weight and the frictional resistances to flow. They thus have an excess pressure above the rocks around them, which is the hydraulic force impelling to further movement. In so far as the specific gravities are concerned, if the water at the point of its elimination has the same pressure as the surrounding rocks, due to the depth of cover, then the excess pressure in the fluid tends to increase with vertical distance above the magma. The viscous resistances to flow tend, on the other hand, to reduce the pressure-difference. This excess pressure is favored by the rise of gases through channels rather than by diffusion through rock, since the viscous resistances are thereby reduced. From the walls of such channels, diffusion and flow into smaller cracks causes a permeation of the adjacent rocks. Meteoric waters, on the other hand, when flowing downward in channels, possess a less hydrostatic pressure than exists in the surrounding rocks, because the two are in equilibrium at the surface and the column of water weighs less than the column of rock. Their permeating power is consequently diminished and in this respect, as well as because of their lower temperatures, they stand in direct contrast to magmatic emanations. Where whole formations of rocks show, then, that they were permeated through and through with water and carbon dioxide when deep below the surface, there are reasons for regarding such waters as of magmatic origin. Examples are seen in chlorite, serpentine and talc rocks, especially when these are derived from igneous masses, for they may contain over

10 per cent by weight of combined water which was not in them at their origin and must have been supplied on a large scale and with a penetrative power which carried it to all parts of the rock mass when undergoing alteration.

Development of Anhydrous or Hydrous Silicates.

In his classic work on metamorphism, Van Hise developed as an important subject that of changes of volume. But he placed the emphasis upon meteoric waters as the especial crystallizing agent of all anamorphic as well as katamorphic changes. On that basis, and on the assumption that water and gases could freely escape, the pressure resulting from depth was shown to tend toward the elimination of both occluded and combined water. The evidence shows this to be really effective in the diagenesis of the sedimentary rocks, resulting in a partial dehydration of kaolin and opal, and often in a complete dehydration of ferric oxide.

Let us look, however, at the pressure effects of deep-seated magmatic waters. They are driven into the rocks by the excess pressure from below. A complete escape above is slow and difficult because of the non-porous and unfissured state of the rocks at great depths. A. C. Lane[16] has shown that under such circumstances the gases may be able to rend the rocks and create a condition of the zone of fracture deep within the zone of flow. In so far, however, as the water as gas or liquid is under greater pressure than the surrounding rocks, it will tend to enter into the form of hydrates, since the hydrated minerals in general occupy less volume than the equivalent anhydrous minerals plus the water in uncombined form. For magmatic waters, therefore, there is opposition between the factors of temperature and pressure. Hydration will, consequently, take place at distinctly higher temperatures than for circulating waters of surface origin.

The importance of this principle can be illustrated by a numerical example based on the extreme or limiting supposition that the water and gases involved as chemical constituents in the reaction can not escape but require space for their existence in the same measure as do the solid constituents. Assume that the density of the water

[16] Bull. Geol. Soc. America, 5, 259-280, 1894.

remains at unity, since increase of pressure tends to increase its density, and increase of temperature tends to decrease it. As the conditions of volume must vary greatly, there is no need here of attempting refinements of calculation.

For computing the density of carbon dioxide or other gases, assume that the physical conditions are those of the critical pressure and temperature of water, 195 atmospheres and 370° C., since this pressure is reached at a depth of about half a mile, and the temperature is one at which hydrates retain much of their water of chemical combination, even under the absence of external pressures as at the surface of the earth. Under these conditions, water also is a gas and incapable of condensing other gases within it. For these conditions the density of carbon dioxide was computed according to Van der Waal's equation:[17]

$$\left(p+\frac{a}{v^2}\right)(v-b)=RT$$

In this

$p =$ pressure in atmospheres $= 195$
$v = 1$ when p is 1
$R = 0.003,66$
$T =$ absolute temperature
$a = 0.009,131$ constant for carbon dioxide
$b = 0.002,427$ " " " "

The density of carbon dioxide (for $p = 195$ and $T = 370 + 273$) is 0.172 of the density of liquid water (at $p = 1$ and $T = 4 + 273$).

Consider the change of biotite to serpentine. As collateral products Van Hise gives kaolin and gibbsite according to the following equation:

$$6KHMg_2Al_2Si_3O_{12} + 18H_2O + 3CO_2 = 4H_4Mg_3Si_2O_9 + 5H_4Al_2Si_2O_9 + 2Al(OH)_3 + 3K_2CO_3$$

It is of course possible that sericite might form to some degree in place of kaolin, gibbsite, and potassium carbonate. The equation will, however, illustrate the problem.

The volume equation as given by Van Hise[18] does not figure in the water and carbonic acid and assumes the elimination of the potassium carbonate in solution. The

[17] Walker's Introduction to Physical Chemistry, pp. 94-97.
[18] C. R. Van Hise, U. S. Geol. Survey, Mon. 47, p. 378, 1904.

reaction shows by this hydration an increase in volume of 14.3 per cent.

The writer has recalculated this equation, first taking in the water as part of the volume with density = 1, but not regarding the $3CO_2$ or $3K_2CO_3$. Instead of an expansion, the result showed a shrinkage consequent upon hydration amounting to 17 per cent. Second, as an extreme condition, the $3CO_2$ and $3K_2CO_3$ were also figured in, the CO_2 being assigned a density of 0.17 and the density of solid K_2CO_3 in the absence of any statement in Watt's Dictionary of Chemistry being arbitrarily assumed as 2.0. This now showed a shrinkage due to hydration and carbonation amounting to 39 per cent. No value is to be attached to this particular equation or to these exact figures, but they serve to strikingly illustrate the principle under discussion.

The rocks are never so impervious as to effectively retain all the magmatic emanations so that that extreme assumption is farther from the truth than the other assumption that the fluids and gases do not enter in any measure into the volume equation. For magmatic emanations the truth must lie between.

The alteration of basic igneous rocks into amphibolites implies, then, very high temperatures in order that dissociation due to temperature may be stronger than the hydration favored by the retention of vapors. The alteration into chlorite and serpentine rocks may also go on at temperatures only less high, provided that they are pervaded under high pressures by abundant magmatic waters. These minerals lose all their water of crystallization only at red heat, about 700° to 900° C., even in the absence of pressure. It would seem, therefore, as if under conditions where water was freely supplied from below and could only escape more slowly above, hydration could go forward at temperatures approaching red heat, distinctly above the critical temperature of water. The curve of relations between temperature and pressure which control this reaction may possibly be determined by laboratory experiment and is a matter of importance for the interpretations of the conditions of metamorphism.

In the light of this reasoning, it appears probable that the regional alteration of the Keewatin lavas into greenstone schists is a mark of pervasive magmatic waters emanating from the Laurentian granites below.

The question is logically raised, why, after the gas pressure has fallen, does not dehydration proceed so as to nullify the previous action? To some degree it may, but a mineral species can exist in a wider range of environment than that which determined its production. The chlorite schists are especially associated with regional mashing and this was without doubt a factor in their genesis. Furthermore, although the excess of gases disappears, the non-porous nature of the rocks does not favor further elimination.

Silication in Relation to Igneous Intrusion.

Geologic observation shows that blocks of marble may be immersed in abyssal magmas and not suffer dissociation of the carbonic acid at the magmatic temperatures and pressures. Such alterations to silicates as occur are the result of reaction with the silica and other oxides which are present, either in the original sediment or carried in from the magma. The experimental work that has been done on the relations of temperature and pressure to the dissociation of calcium carbonate has been reviewed by Königsberger,[19] and on account of the wide range of pressures represented in the experimental data, he selects the work of Riesenfeld[20] for extrapolation; there is, however, a considerable disagreement of authorities, and the figures may be only approximate. The table is of sufficient interest to be given here.

Temperature Centigrade	Pressure Atmospheres
910	1
1000	4
1100	20
1200	170
1300	2,600
1400	80,000

The dissociation curve supplements the evidence of wollastonite as a contact mineral which cannot exist above 1150° C. in showing that the inclusions of marble have never been heated to a temperature as high as 1300° C., since this would require a depth to prevent dissociation greater than that given by the geologic evidence.

[19] J. Königsberger, N. Jahrb. f. Min., etc., Beilage Bd. 32, p. 124, 1911.
[20] E. H. Riesenfeld, Jour. Chim. Phys., 7, 561, 1909.

The pressure and temperature relations which control the mutual displacing power of CO_2 and SiO_2 form a problem somewhat analogous to, and yet different from, that discussed for hydration and dehydration. It has recently been discussed with the aid of a diagram by Goldschmidt,[21] who bases his law upon the curve of vapor tension of calcium carbonate. He does not, however, take up the aspect more especially developed here—the increase in the vapor pressure of carbon dioxide which would be due to magmatic emanation coming in from below and without free escape above. By raising the vapor pressure, the formation of carbonates is theoretically favored. Nevertheless, in the case of such hydrated rocks as serpentines and chlorite schists, the carbonates are of secondary importance and consist of intermixed calcite. This is true notwithstanding the added fact that carbonates possess in general smaller molecular volume than the corresponding silicates.[22] It would appear, therefore, that such carbonates as form are largely eliminated because of the possibilities of the slow escape of the gases and the solubility of the carbonates in water with abundant carbonic acid. It would appear further, however, that where such hydrous silicates as serpentine, talc, chlorite, sericite, kaolin, epidote, and zeolites are formed, either carbon dioxide was only sparingly present in the hydrating waters or else carbon dioxide can not displace silica from any oxides except lime and soda and in part potassa at those temperatures where hydration goes on to a greater or less extent, and especially hydration by magmatic waters. Königsberger mentions further that in water solution at 260° C. silica displaces carbonic acid from lime. This laboratory evidence, as well as the mineral relations just cited, appears to show that silica displaces carbon dioxide at temperatures well below those determined by Goldschmidt by

[21] V. M. Goldschmidt, Die Gesetze der Gesteinsmetamorphose mit Beispielen aus der Geologie des südlichen Norwegens, 1912.

[22] [The reaction is also discussed by Johnston and Niggli in their paper on the principles underlying metamorphic processes (Jour. Geology, **21**, 481-516, 588-624, 1913). In most of their discussion they assume that CO_2 may escape as produced. They find that temperature is much more important in determining the direction of the reaction than pressure. However, "it is true that pressure is required in order to retain the volatile components." They further emphasize the important distinction between uniform and non-uniform pressure, and show on pages 614-615 that stress or non-uniform pressure will cause reactions between carbonates and silica with the development of CO_2 to a much greater extent than would be likely in the absence of stress.]

means of the tension curve. Chemical affinity, reversible with change of temperature, is the controlling condition. The temperature limit is sufficiently low so that notwithstanding the abundant presence and high pressure of carbon dioxide in the contact zone, silication is the characteristic process. Only on the outer borders does the reaction become reversed.

Relation of Magmatic Gases to Atmosphere and Ocean.

It is held by many geologists at the present time that the gaseous and liquid envelopes of the earth are to be looked upon as the differentiated and unconsolidated residues of the igneous rocks. Most commonly, however, they are regarded as having had approximately their present volume since the closing of the formative stages of the earth. The emphasis which is here placed, however, upon the great volumes of gas liberated in igneous invasion, and the very considerable extent of post-Cambrian batholithic invasion only partially revealed by erosion, suggests that the atmosphere and ocean may have received notable additions since the beginning of the Laurentian, and appreciable additions even since the beginning of the Paleozoic. To make a guess in order to give concreteness to this statement: it seems not improbable that the ocean waters may have increased 25 or 50 per cent in volume since the beginning of the Keewatin lava flows, and 5 to 10 per cent since the beginning of the Paleozoic. The nitrogen of the air has perhaps increased equally, with the result that the atmosphere may now be of a very different constitution than in the earliest geologic ages.

Limited Depth of the Zone of Anamorphism and Rock Flow.

The earth's crust, when under tangential compression, must yield along its zones of greatest weakness. Where geosynclines have permitted the accumulation of sediments, these may reach to depths as great as six or eight miles. The deeper parts must become condensed, cemented, and hardened; not softened into a sub-mountain liquid as was postulated by an older theory. But the shales remain weak and the horizontal bedding is a structural weakness even in the rocks of strongest inherent composition. Geosynclines, then, even without the influence of subjacent igneous action, are zones of weakness.

There is, however, another way in which the crust may be weakened which seems to the writer to be equally important: the weakening from below by the rise along axial zones of orogenic batholiths. Not only is the outer crust dissevered from the inner portion, but the latter may be temporarily destroyed to an unknown degree. The batholithic covers are of irregular form and poorly adapted to resist stresses. It would appear that the rising heated emanations carry high temperatures with them far upward in the crust. The conditions for anamorphic recrystallization may thus be carried to within a mile or two of the surface. The crumpled and foliated structures of the zone of flow and the recrystallization of the rocks may thus not necessarily be restricted to profound depths in the crust.

Van Hise located the top of the zone of rock flowage as probably at a depth of five to seven miles, but recognized that it must vary widely with variation in the controlling conditions and would be of least depth for the argillites. F. D. Adams has shown experimentally, however, that cubic compression greatly increased the strength of rocks, and that small cavities could remain open at temperatures and pressures such as are found at depths of eleven miles and more in the crust. On the other hand, in eastern Massachusetts, Carboniferous sediments are transformed into schists and sandstone beds are transformed to quartzites; yet these sediments are, so far as known, parts of the last formations deposited before the occurrence of the orogenic revolution which led to their metamorphism. It is not likely that they have ever been profoundly buried, a depth of a mile or at most two miles being the greatest probable depth which can be assumed. In other regions, suggestions of similarly shallow batholithic intrusion are to be found,[23] but the generality of this conclusion is founded upon another line of evidence.

It has been shown by various authors that the soda derived from the weathering of plagioclase feldspar is carried to the sea, and except for the insignificant amounts precipitated in salt deposits or held in sediments as connate waters, it must have accumulated through geological time. But the volume of the sea and its chemical composition are known with fair accuracy. Therefore the volume of the average igneous rock needed to supply the sodium becomes determinable. Allowing one third of the

[23] J. Barrell, U. S. Geol. Survey, Prof. Paper 57, p. 166, 1907.

sodium to be retained in the sediments in insoluble form, as shown by their average composition, the salt of the sea requires the erosion of a shell of igneous rock 2,200 feet thick enveloping the globe. If the erosion be regarded as restricted to the continents, and their area be taken as 28 per cent of the area of the earth, the equation would require the erosion of 7,900 feet of rock. The actual average erosion from the present land areas has probably been between these two figures, since ancient lands such as Appalachia, which have supplied much sediment, are now in part submerged.

The erosion, however, has been very unequally distributed. No igneous rock has been removed from the broad interior of the United States since pre-Cambrian times, and the same is true of other wide areas. Therefore there is room for the removal of many miles of igneous rock from mountain axes, not counting the erosion and re-erosion of the sedimentary formations. But allow for the demands of Paleozoic, Mesozoic, and Cenozoic erosion of igneous rocks, and the balance left to be assigned to pre-Cambrian erosion is materially reduced. Under the most favorable assumptions it can hardly be much over a mile in thickness, and if allowances are made for later continental fragmentation, it may not be much over half a mile.

Now the metamorphism of the basement complex is universal, and the batholithic exposures cover enormous areas. From such regions the older lavas have been removed, and erosion has bitten deeply into the underlying granites. But how deeply? For any particular region it may be five miles, ten miles, or even more, but considering the limitations placed by the salt in the sea, it would seem conclusive that the average erosion which has exposed the Archean zone of anamorphism and rock flow has not been more than a mile. Even the metasediments of the ancient cover are counted into this estimate, for although their removal would not add a fresh supply of salt, their original formation had given it, and by just so much had diminished the measure of later erosion. It would appear fairly certain that the profound metamorphism of the Archean complex does not imply the necessity of formation beneath from five to ten miles of cover.

This line of evidence, although indirect, is perhaps one of the strongest of many which go to show that the conditions of regional metamorphism are bound up with

batholithic invasion. How, then, shall the geologic evidence be reconciled with the laboratory demonstrations of Adams? This is not a conflict between facts and an imperfect theory, but rather between two categories of facts. Experimental work as conducted by Adams requires temperatures and pressures for rock flowage far in excess of the conditions implied by the geologic evidence. It is the business of theory to explain the paradox.

The theory of rock flowage, in the form stated by Van Hise, calls for an intermediate level. What adjustments of this theory are needed to bring harmony between it and the apparently diverging facts? It appears that the most probable solution may be found by invoking the high temperatures and abundant crystallizers which must be present in batholithic roofs.[24] Let crustal compression operate at the same time and stress-differences arise through the crust. But the molecules under strain are more soluble, energy is released by their solution, and they are precipitated free from strain. The energy absorbed in deformation is transformed into heat and assists further in the process of recrystallization.

The phenomenon of rock granulation is suggestive of a very considerable depth of cover, yet even for this the geologic evidence does not support the view that any such profound depth is necessary as the laboratory work of Adams would seem to imply. It occurs especially in the granite gneisses, massive and resistant formations. In part it seems to be related to a last stage in crystallization accompanied by movements in a very viscous magma. The granulation of phenocrysts in rhyolite surface flows offers a suggestion of the process. In part the presence of foliation at right angles to the pressure may prevent shearing on major diagonal thrust planes and compel each layer to yield independently by intramineral shear.

(To be continued)

[24] Daly has presented, in a paper on metamorphism in volume 28 of the Bulletin of the Geological Society of America, a similar argument that the depth of pre-Cambrian metamorphism was not great; he suggests that it is to be explained by a steeper thermal gradient in the early history of the earth. This is one factor in the present suggestion, the other being emanations from the same magma that produced the steeper thermal gradient.

ART. XII.—*On the Permian of Coahuila, Northern Mexico;* by EMIL BÖSE.

In 1913, Doctor Erich Haarmann published his discovery of marine Permian beds in northern Mexico.[1] This discovery was rather surprising, as everywhere in northern central Mexico the lowest exposed rocks had seemed to be of the Upper Jurassic. Furthermore, there did not appear to be any indications of large dislocations, which alone could apparently be the explanation of an exposure of lower beds, as the Jura-Cretaceous series seemed to be uninterrupted at every point of this region where the geology was known. Haarmann on a very rapid journey found the Permian beds on the Hacienda de las Delicias, 68 kilometers north of San Pedro de las Colonias, at the foot of the high Sierra del Sobaco, in the southern part of the state of Coahuila. The geographic position of these Paleozoic beds made the occurrence still more surprising, since a little south of San Pedro the Upper Jurassic is exposed in many places (Concepción del Oro, Mazapil, Sierra de Ramirez, San Juan de Guadalupe, etc.). Moreover, west of San Pedro de las Colonias, the same conditions had been observed at San Pedro del Gallo, Durango, and as it is well known that the Jura-Cretaceous series exists in many parts of eastern Chihuahua, it therefore seemed very improbable that any Paleozoic rocks were exposed in this region. On the other hand, the discovery could scarcely be doubted, especially since Haack published[2] an account of the little fauna of Permian age collected by Haarmann.

Haarmann distinguished two different Paleozoic formations at Las Delicias. He considered as the older one a series of at least 2000 meters thickness, the lower portion of which is largely volcanic in nature and consists mainly of pebbles and cemented sands; upward the pebbles grow smaller and decrease in quantity; thick beds of sands derived from volcanic rocks predominate and might at first view be taken for weathered volcanics; still higher follow dark to black marly shales and marls, which contain geodes and beds of dark limestone. Haar-

[1] Erich Haarmann, Geologische Streifzüge in Coahuila. Zs. deutsch. geol. Ges., 65, 1913, Monatsberichte.

[2] Wilhelm Haack, Ueber eine marine Permfauna aus Nordmexico nebst Bemerkungen ueber Devon daselbst. Zs. deutsch. geol. Ges., 66, 1914.

mann called this series the *Delicias beds* and considered it as pre-Permian, stating that remains of coral reefs were lying unconformably on the Delicias beds in several places, and that this higher series consists of a yellowish gray, solid, massive limestone, especially well exposed at the Pichagua. The limestone contains the faunule described by Haack, composed of the following species: *Cyathaxonia girtyi* Haack, *C.* sp., *Cladopora spinulata* Girty, *Streptorhynchus*(?) sp. 1, *S.*(?) sp. 2, *Richthofenia permiana* Shumard, *Spiriferina haarmanni* Haack, *S. hilli* Girty, *Hustedia meekana* Shumard, *Dielasmina guadalupensis* Girty, *Dielasma* cf. *biplex* Waagen.

Haack also found fossils in rocks of the Delicias beds. One of these he considered to be *Gypidula* aff. *pseudogaleata,* and others are a goniatite apparently related to *Sporadoceras,* and a tabulate coral nearly related to *Alveolites goldfussi* Billings. In thin slides remains of Foraminifera were seen. Relying on his determinations of the few fossils gathered from the Delicias beds, Haack referred the latter to the Devonian, but thought that beds of other age might be contained in the same series.

From the very beginning, it was evident that the discovery of Haarmann was of the greatest importance for either the tectonics or the stratigraphy of northern Mexico. I therefore had a great desire to visit the locality myself and to study the relations between the Permian and the younger rocks, as well as that between the Permian and the supposed Devonian. Unfortunately, for many years the Hacienda de las Delicias has been the seat of revolutionary chiefs and a visit to it was practically impossible. However, when political conditions in that part of the country improved, during the early part of the summer of 1920, I made two trips to the Hacienda de las Delicias and made the field studies above outlined. Of my results, which differ somewhat from those of Haarmann and Haack, the following statement gives a preliminary account.

My first visit was to the limestone cliff known as the Pichagua, lying about 15 kilometers north of the hacienda buildings and in the foothills of the Sierra del Sobaco. I collected the fauna described by Haack, and other forms, and soon gained the impression that the Pichagua cliff was nothing other than a lenticular thickening of a limestone bed intercalated in the Delicias series. A second visit confirmed me in this belief; I followed this limestone

toward a small creek, where it could be easily observed that it was normally lying between the sandy and shaly beds of the Delicias formation. I then resolved to study the relation between the cliffs and the Delicias beds in another portion of the valley where I could also find sufficient drinking water, and where the Delicias beds are much better exposed than in the Arroyo de Wenceslao. This place is a few kilometers farther south, near the Noria de Malascachas, where a well dug in the Delicias beds contains plenty of good water, a rather scarce commodity in this region.

Here the Delicias beds compose the lower half of the Sierra del Sobaco and show in several places cliffs of dark limestone. I tried to make a cross-section and to collect as many fossils as possible.

A little east of Noria de Malascachas the Delicias beds are cut off by a north-south fault which toward the east brings the series into contact with a block of Cretaceous limestone. The lowest portion of the Delicias exposed here consists mainly of dark, thin-bedded or laminated clays, alternating with thin to thick beds of greenish to yellowish sandstone, mostly of igneous detritals. Sometimes the clays contain concretions of dark limestone with scattering remains of undeterminable brachiopods, and often *Fusulina.* The beds show a strong dip (45° and more) toward the west. These rocks continue for about 150 to 200 meters higher stratigraphically; then the sandstone becomes coarser and passes into a conglomerate, mainly of igneous material, the pebbles being large and well rounded. Upward in the conglomerate occur calcareous concretions which also pass into the dark clay and a few meters higher consolidate into a bed of limestone. This forms a small cliff on the crest of a spur of the mountain but continues in the creeks on both sides of the spur, without any interruption, as a solid bed of dark limestone, becoming somewhat thinner with distance from the lenticular swelling of the cliff. Higher stratigraphically the bed of limestone dissolves into a great number of rounded blocks. These apparently are only concretions imbedded in dark clay, and about half a meter above the solid bed of limestone the dark clay predominates, reproducing here, as elsewhere, intercalated beds of greenish sandstone. There can be no doubt that the limestone is interbedded in the clay, sandstones, and conglomerates of the Delicias beds, and that the little cliff

is only a local and lenticular swelling of the limestone, as the fossils both in the cliff and in the intercalated bed of limestone are the same. I have called this place Malascachas No. 1. The limestone is full of fossils nearly everywhere, and I could distinguish the following forms: *Fusulina elongata, Composita* cf. *subpolita, Spiriferina, Productus, Martinia, Enteletes,* and *Camarophoria* aff. *mutabilis.*

The fossils are well preserved; the limestones at times are wholly made up of *Fusulina,* and the most common forms of brachiopods are a rather large *Enteletes* and a *Composita.*

About 20 meters higher stratigraphically occurs another calcareous bed intercalated in the dark clays and sandstones. It does not form a cliff here, but continues with about the same thickness in the creeks on both sides of the spur. This upper limestone is not as massive as the lower one and is rather more thin-bedded or laminated and somewhat marly, in such a manner that in places the fossils weather out free and can be picked up loose. Some of the thin layers are made up of *Fusulina,* while others are composed entirely of brachiopods. The fossils are somewhat crushed, but I could distinguish the following forms in this locality, which I call Malascachas No. 2: *Fusulina elongata, Productus* aff. *gratiosus, P.* sp., *Spirifer* aff. *fasciger, Composita* cf. *subpolita, Hustedia* aff. *meekana, Dielasma, Uncinulus,* and *Lyttonia.*

The next portion of the rock section is mostly composed of dark clays alternating with greenish and brownish sandstones, but part of it is not very well exposed. About 200 meters stratigraphically above the last locality the sandstones again dominate, showing here a yellow to brown or even reddish color. Interbedded in them occur zones of coarse conglomerate containing concretions of limestone, while in other places a similar dark limestone forms beds in the sandstone. I call this locality Malascachas No. 3, and from it I got the following forms: *Waagenoceras dieneri, Stacheoceras* sp. nov., *Martinia, Reticuliar (?), Composita* cf. *subpolita, Hustedia* aff. *meekana, Richthofenia* cf. *uddeni, Myalina* aff. *permiana,* corals and gastropods.

The ammonoids are very well preserved, and both forms show the suture lines clearly and are easily determined. The brachiopods are somewhat crushed, but

probably can be determined specifically. The *Stacheoceras* belongs to the group with numerous saddles, and resembles forms from the Sosio beds of Sicily. Of *Richthofenia* I found only one specimen, but the other brachiopods are numerous. The small *Myalina* is very common.

From this level upward in the series clays and sandstones predominate; but about 50 meters higher we find a zone of imperfectly bedded dark gray limestone containing silicified fossils, mainly those described by Haack from the Pichagua cliff. Then follows more dark clay and sandstone, and finally a bed of dark limestone with fossils, only about half a meter thick. Above comes more dark clay and some sandstone and then a mass of partly well bedded dark gray siliceous limestone at least 20 meters thick. I call this locality Malascachas No. 4. The limestone here contains a great number of silicified fossils, most of which belong to *Richthofenia* cf. *permiana,* and can be collected by the hundreds. There are also corals, and *Composita* aff. *subpolita, Uncinulus,* and other brachiopods, as well as Bryozoa. As in all the lower beds, we likewise frequently find here crinoid stems, some of rather large diameter.

In its upper portion the limestone dissolves into blocks and concretions imbedded in dark clay, then follows more dark clay for about 20 meters, and this in turn is covered by a green sandstone of igneous detritals.

This sandstone is unconformably overlain by light colored hard limestone containing oysters and, a little higher up, *Orbitolina texana.* The limestone is medium bedded and has a thickness of about 50 meters; in its upper portion it passes into dark dolomites and light colored thick bedded limestones alternating with beds of white gypsum. The dolomite frequently contains in the lower portion beds composed of *Monopleura* and higher occur thick beds of light colored or reddish limestone almost entirely composed of medium-sized *Caprina* or related genera. Then follows the main mass of the middle Cretaceous limestone composing the upper portion of the Sierra del Sobaco.

The gypsum band of the Cretaceous is extremely characteristic and can be distinguished from afar. It forms a light-colored band along the whole Sierra del Sobaco, and where the large north and south fault cuts the beds, we see one whitish zone of gypsum high in the mountains

and a second lower one a little above the plain of the valley; the latter always lies about 50 meters above the limit between the more strongly inclined Permian and the less inclined Cretaceous. I first noticed this gypsum bed immediately above the Hacienda de las Delicias buildings and could follow it all through the range, but it also exists east of the broad valley of Las Delicias and in the lower portion of the Sierra del Venado.

The conditions described above show clearly that the Pichagua limestone and the Delicias beds are both of the same age and represent a portion of the lower Permian (Permo-Carboniferous). The occurrence of *Waagenoceras dieneri* Böse proves that these beds correspond to a rather high horizon of the lower Permian, the zone of *Waagenoceras* or the Word formation of the Glass Mountains and the Delaware beds of the Guadalupian in the Delaware Mountains of Texas. I have found the same *Stacheoceras* sp. nov. or a very nearly related form in a collection of fossils from the Delaware beds made by Charles L. Baker in the hills south of Guadalupe Point in northwestern Texas. There is, however, a possibility that the lower portion of the Delicias beds corresponds to the Leonard formation of the Glass Mountains, but this can not be established as yet, since no *Perrinites* has been found in it; the frequency of *Fusulina elongata* makes it appear rather probable that this part also belongs to the zone of *Waagenoceras*.

All the other fossils confirm our determination, especially the well preserved and very common *Fusulina elongata*. I have found this form not only in the section above Malascachas, but practically everywhere in the black limestones of the Delicias beds, from the Cañon Angosto to the slope of the Sierra del Sobaco above the Pichagua cliff.

The higher limestones of the Delicias beds, which in general are less dark and much more siliceous than the lower ones, often contain great quantities of crinoid stems; near the Puertecito (in the sunken block east of the great fault) there are even actual crinoid limestones which rarely show any other fossils.

The Delicias beds do not contain any Devonian species, as Haack supposed. If the determinations of this author are correct, he must have had some Devonian forms in a pebble out of the conglomerates, but as he says expressly that his *Gypidula* aff. *pseudogaleata* occurs in the cal-

careous cement of the conglomerate, I fear that he must have confounded some other brachiopod with *Gypidula;* unfortunately he does not give a figure of this specimen. Our faunas are so rich in specimens and so evenly distributed over practically the whole thickness of the Delicias beds, that there does not remain the slightest doubt about the age of the entire series.

The petrographical character of the Lower Permian of the Sierra del Sobaco is entirely different from anything of the same age which I have seen in the Trans-Pecos region of Texas or in New Mexico. The upper limestone containing *Richthofenia* and those of the Pichagua cliff, as well as others in the higher portion of the Delicias beds, resemble to a certain degree the Word limestone of the Glass Mountains, but the former are much more irregular in distribution and far less in thickness. The sandstones and conglomerates composed of igneous detritals are different from anything I have seen in Texas or New Mexico. I may also mention that near the buildings of Las Delicias the Cretaceous rests on an intrusive mass of Paleozoic age, showing an abraded surface and belonging either to the Permian or to a series immediately below this formation. The intrusive is of syenitic character. It is certainly not a post-Paleozoic intrusion, as it is overlain by a green sandstone composed of its material, about one or two meters thick, and in no place intrudes farther into this sandstone or the Cretaceous limestone. These conditions are very well exposed at and between the two springs which flow down to the hacienda.

Notwithstanding these marked petrographical differences, the Permian of Las Delicias is most probably a continuation of the Texas Permian, as is shown by the character of the fossils.

Our section shows also the reason why the Paleozoic rocks appear here on the surface of the Mesa Central. The whole of the Trias-Jura-Neocomian is missing; we have here probably the southernmost part of the large Trias-Jura continent of Texas and New Mexico. The Aptian, represented by the limestone and gypsum zone with *Monopleura* and *Orbitolina texana*, rests unconformably on the Lower Permian; the beds of the older formation also show a much stronger dip than those of the Cretaceous, and the strike is somewhat different. The Trias-Jura continent did not extend much farther

south, because south of the depression between Torreon and Saltillo we find again the uninterrupted Jura-Cretaceous series. The probable west and east limits of this continent will be discussed at another time.

I have tried to find the continuation of the Permian farther north, and for this purpose have crossed the desert between Cuatro Ciénegas and Sierra Mojada, but have failed to find it there, as everything is covered by middle and upper Cretaceous. Of course, there is a possibility that Paleozoic rocks may be exposed farther north.

With our conclusion that the Delicias beds and the Pichagua limestone are of the same age, there arises the question which of the two names should persist. I think that it would be best to retain the name Delicias, not as a denomination of a horizon but as that of a facies. We can not very well take the name of a small cliff of limestone for this important series, but had better apply the name of the hacienda in the territory of which lie all of the beds described.

Monterey, Nuevo Leon, Mexico, August, 1920.

ART. XIII.—*On the Occurrence of Structures like Walcott's Algonkian Algæ in the Permian of England;* by OLAF HOLTEDAHL.

During his studies on the Paleozoic rocks of Finmarken and Bear Island, the writer became acquainted with the peculiar organism-like structures in dolomites and limestone which American paleontologists have generally referred to *Cryptozoon*. In a summary of my stratigraphical results in Finmarken published in this Journal in 1919,[1] the opinion was stated that the *Cryptozoon* "species," such as *Gymnosolen ramsayi* described

FIG. 1.—Four-fifths nat. size. Compare with *Newlandia frondosa* Walcott.

by Steinmann from northern Russia, can not be regarded as real fossils which deserve generic and specific names, but rather that this type of sedimentary rock must be considered to represent "a chemical precipitation, one, however, that probably came into existence through the organic processes of living organisms." Accordingly, as a general term for these structures, which appear to be genetically related to oolites, it was proposed that we should use Kalkowsky's name stromatolites.

As to the kind of organisms which may have played a part in the process by which the stromatolite laminæ were precipitated, I mentioned, among others, the cells of blue-green algæ described by Walcott from *Camasia spongiosa*

[1] Vol. 47, p. 96.

in his widely known paper on the "Pre-Cambrian Algonkian algal flora."[2] Besides the species of *Collenia*, which certainly also represent only variations of the stromatolite structure, Walcott described a great number of "species" of algæ whose beautiful structure and great geologic age have caused no little sensation among geologists. From the Newland limestone of the Belt series are described no fewer than six new genera, *Newlandia*,

FIG. 2.—Two-thirds nat. size. Compare with *Newlandia frondosa* Walcott.

Camasia, Weedia, Kinneyia, Greysonia, Copperia, the first mentioned with four, the rest with only one species.

Recently I happened to see several of these types of structures in the Permian limestones of England and should like to draw the attention of American geologists to their occurrence. During a very short stay in Newcastle-upon-Tyne in June 1920, my friend Leonard Hawkes, of Armstrong College, who knew of my interest in these peculiar sedimentary structures, arranged an excursion to the Permian magnesian limestone of the Durham district in order to have me see its so-called

[2] C. D. Walcott, Smithson. Misc. Coll., 64, No. 2, 1914.

concretionary limestones. I was fortunate in having as a guide Doctor D. Woolacott, who has studied the district in great detail and published several important papers on its stratigraphy and tectonics. We visited especially the extensive Fulwell quarries, where the concretionary structures are seen in wonderful variation. Here there are concretions of the more ordinary sort, *e. g.*, the "cannon ball" and the "botryoidal" types, along with a great display of other more cellular structures, and

FIG. 3.—Three-fourths nat. size. Compare with *Newlandia frondosa* Walcott.

among these I recognized at once several types which struck me as being identical with those shown by Walcott in the splendid illustrations accompanying the paper cited.

The many curious structures of these Permian limestones were described in 1835 by Sedgwick,[3] whose very detailed and accurate descriptions give a clear account of the great variety of these stromatolite structures in the Permian limestone of eastern England. His illustrations,

[3] A. Sedgwick, Trans. Geol. Soc., London, 2d ser., 3, 37-124.

on the other hand, give no very distinct idea of their character. In 1891, Garwood published a paper entitled "On the origin and mode of formation of the concretions in the magnesian limestones of Durham,"[4] treating, however, mainly concretions of the more ordinary types, some of which are depicted. In the British Association report for 1900, Abbott has an abstract of a paper on these concretionary types, and two years later another very short abstract.[5] Trechmann in 1914 writes on "The lithology and composition of Durham magnesian limestones" and in an earlier paper has remarks on the concretionary structures.[6] Other very important contributions are Woolacott's papers of 1912 and 1919.[7]

FIG. 4.—Four-fifths nat. size. Compare with *Greysonia basaltica* Walcott.

The purpose of the present article is not to give a detailed description of the Durham concretions, since such may be found in the papers above mentioned, and since a full description with necessary illustrations will, it is to be hoped, soon appear from the English investigators, but rather to draw attention to the resemblance of some of these Permian concretionary structures to those of the Algonkian Newland limestone, and to illustrate this likeness by photographs of specimens which were collected during the excursion and kindly sent to Kristiania by Mr. Hawkes.

[4] E. J. Garwood, Geol. Mag., dec. 3, vol. 8, 434-440.

[5] G. Abbott, Rept. British Assoc. Adv. Sci., for 1900, pp. 737-739; **Quart. Jour. Geol. Soc., London, 59**, 51, 1903.

[6] C. T. Trechmann, Quart. Jour. Geol. Soc., London, **70**, 232-265, 1914; **Ibid., 69**, 184-218, 1913.

[7] D. Woolacott, Proc. Univ. Durham Phil. Soc., **4**, 241, 1912; **Geol. Mag.**, dec. 6, **6**, 452, 1919.

Structure of the Newlandia type.—Walcott's diagnosis of *Newlandia* is (p. 104): "More or less irregular semi-spherical or frondlike forms built up of concentric, subparallel, subequidistant thin layers that may be connected by very irregular, broken partitions." By comparing my figure 1 with Walcott's plate 6, especially figure 2 (of *N. frondosa*), the strikingly similar features will be seen. This likeness is still greater between my figure 2 and Walcott's plate 7, figures 1 and 2, where the

FIG. 5.—Same specimen as in fig. 4. Vertical section through tubes.

concentric laminæ are less strongly and less regularly curved. My figure 3 shows a structure similar to his figure 1 of the same plate, yet with somewhat thinner and regularly spherical laminæ. A small ball-like specimen in my collection, 6 cm. in diameter, shows a concentric structure with the same very slight thickness of the laminæ as in Walcott's illustrations of *N. lamellosa*, plate 10, figures 1 and 2. There is no doubt that the same structure can easily be found in larger masses, giving a picture like those of Walcott.

Structure of the Greysonia type.—Walcott's diagnosis of *Greysonia* (p. 108) reads as follows: "Irregular, cylindrical or tubular growth with relatively thin walls except at the union of three or more tubes, where the walls are thickened ... The tubes are large, irregularly rhomboidal or pentagonal in section with the interior now filled in with a dark bluish-grey limestone. The walls

or partitions represent the deposit made by the algæ and are now a buff-colored and grey magnesian limestone. The ends of a group of the tubes filled in with the limestone appear like a group of miniature basaltic columns, and the base or lower side of the same tubes has irregularly oval and round, concentrically marked forms that appear to be the filling of the ends of the tubes ... The walls are arranged in echelon and the fillings break out as plates of columns."

FIG. 6.—Three-fifths nat. size.

As to the mode of growth, Walcott states: "As far as indicated by the specimens collected by Mr. M. Collen the cellular structure grew with the tubes more or less parallel to the bottom and in some instances upright or at right angles to the bottom." Corresponding to this type we have the "irregular cylindrical or conical pillars" of Sedgwick and the "basaltiform" type of Abbott. I have a specimen of this type and it is shown in figures 4 and 5. The likeness between figure 4 and Walcott's cross-sections of *G. basaltica* (pl. 17, fig. 2; pl. 18, figs. 1, 2) is very striking indeed. In the Fulwell quarries the tubes also occur at very different angles. Walcott's genus *Copperia* likewise belongs to this type of structure.

As to *Camasia*, I have no specimen that can be directly compared with those of *C. spongiosa* figured by Walcott. It should not be difficult, however, to find this type in the Fulwell quarries if it were looked for especially. In

places the specimen shown in my figure 3 shows a similar spongoid surface to that of Walcott's plate 12, figures 1 and 2, and another specimen in my collection has a distinct tubular type; the one of which a section is illustrated in figure 8 resembles considerably the *C. spongiosa* of Walcott's plate 9, figure 2.

It seems to me unlikely that anyone who compares the illustrations here mentioned will doubt that the structures from the Newland limestone of western America and

FIG. 7.—Showing the vertical tubes strongly; seven-eighths nat. size.

those from the Permian limestone of England are identical in general character, or that they must have had a similar origin.

It can not be said, because these structures which Walcott has described as pre-Cambrian algæ are also found in the English Permian, that this argues against their being of direct or indirect organic origin. On the contrary, we may well expect similar structures also to occur in post-Algonkian formations, and Walcott directs attention to this possibility, since the blue-green algæ still are active as precipitators of lime. However, there are other facts that oppose rather strongly the mode of formation which he has assumed. Personally, I was in the quarries only a couple of hours, and therefore do not feel competent to go fully into the very complicated question of how these very remarkable structures were formed. It is evident, however, from what has been written about them by the English workers, that all who have studied these structures regard them as not having

been formed primarily, on the sea-bottom, but secondarily, through alterations in the rock.

Sedgwick holds that the particles of the rock, "after deposition, seem to have undergone great internal movements,—to have run into lumps and masses more or less crystalline," etc. And he states concerning some plates of the rocks which assume a discoidal form "and at first sight might be mistaken for large *Nummulites*" (cf. the plate-like *Newlandia frondosa*, Walcott's plate 6, figures 1-3): "That these changes took place after the deposi-

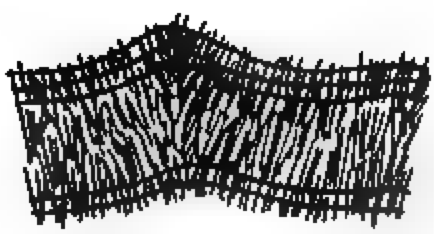

Fig. 8.—Above, one of the Fulwell quarry structures. Below, a laminated fibrous crystalline aragonite. Both natural size.

tion of the rock, is rendered probable by the additional fact, that the laminations of the beds may be often observed to pass (without any deviation) through the various subordinate concretionary masses." Another fact that indicates the secondary origin is that "the same bed which in one end of a quarry is homogeneous, in the other is almost made of these singular concretions."[8] It is also evident that Abbott and Trechmann regard the structures as secondary, and Woolacott states in 1919:[9] "As Sedgwick pointed out in 1835, the concretions were formed after deposition, and I have shown that they must have been mainly produced before the folding and dislocation of the strata took place." Again he says: "The

[8] Op. cit., pp. 89, 95, 97.
[9] Op. cit., p. 463.

concretionary limestones were originally dolomitic limestones, and there can be little doubt that these rocks were impregnated with sulphates and that the solution of these brought the bed into a condition which gave the concretionary forces full play; and further it would seem highly probable that the complicated structures occurring in these rocks were mainly produced when the beds were saturated in solutions of calcium sulphate containing colloidal organic matter. It is the presence of this latter matter that causes the spheroidal condition.'"[10]

From a study of the few specimens at hand, the inorganic and secondary character of the structures seems also to be evident. What is observed at once, both in the field and in the literature, is that there generally is in these structures every transition between the various types, and that hence they can not well have the value of "genera" and "species." Abbott, who speaks of the "hundred or more patterns met with," like Woolacott, distinguishes several main types (Abbott's honeycomb and coralloid; Woolacott's spherical and cellular), and these again each divide into minor varieties, but that is all that can be done with them. We may find any sort of variation and transition. As Sedgwick says, there is no end to the modifications. The thickness of the laminæ varies, and the distinctness of the radiating structure as well. In figure 6 very different characters can be seen in this one specimen. In the lower part, only the concentric laminæ are seen, while in the upper left-hand part, radially arranged tubes are very distinct. These tubes or rods come into existence by more or less conspicuous thickening of the concentric laminæ at regular intervals. The tubes can also be very slender, and the concentric laminæ only slightly indicated, as in figures 7 and 8 (top).

One feature that does not vary, however, is the arrangement of these radiating rods or indications of rods vertical to the concentric laminæ. Where the lamination curves, the directions of rods change correspondingly. In the upper part of the specimen illustrated in figures 4 and 5, the tubes are straight and parallel, and here we find a totally regular lamination, with the laminæ in a

[10] The possibility of a primary deposition has, however, been mentioned by Jukes-Browne (Geol. Mag., 1891, p. 528), and B. A. Green has suggested (see Woolacott 1912, p. 270) that the rock was originally a tufaceous deposit, the concretions being in part due to irregular precipitation, and in part to later rearrangement.

plane and quite parallel. This lamination is, however, of another type than the more coarse irregular one which is seen in the lower part of the same specimen. This exceedingly fine lamination seems, to judge from the pieces at hand, to be secondary in relation to the coarser one. A similar lamination can also be observed in figure 6, cutting through the coarser structure. A fine lamination that might correspond to the one seen in my figure 6 seems also to cross the coarser structure of the *Newlandia frondosa* in the specimen depicted in Walcott's plate 6, figure 3. This lamination probably corresponds to the "bands" of Abbott (1900), which, as he says, "run across the beds at various angles." He states further that "the rods invariably start from the last-mentioned bands, and may be seen at every angle."

The regular, "basaltic" tubes, the *Greysonia* structure, thus are connected with one type of lamination, the more irregular radiating rods or indications of rods of the *Newlandia* structure with another, and as both types of laminæ are seen crossing each other, they can not well both represent a primary structure, coming into existence at the time of deposition. Even without this crossing, one would judge that a structure like that shown in figure 4 is too geometrically regular to have anything to do with organic deposition. Walcott also remarks (p. 109) concerning the *Greysonia* that "it is difficult to conceive of the tubular structure of *Greysonia* as a deposit made by algæ, but with the example of the varied forms of recent deposits made by the blue-green algæ (Cyanophyceæ) and the other fossil forms described in this paper we are prepared to consider *Greysonia* as of algal origin."

As far as can be judged from my specimens, the coarser *Newlandia* structure cannot be of organic origin. An individual like the one in figure 3 shows so great a regularity that only one of two conclusions can be drawn: either it represents a true organic skeleton, like that of a huge *Nummulites* or *Receptaculites*, or it must be wholly of inorganic origin. The recent "lake balls" that Walcott figures have no regular radiating structure at all, nor should such a structure be expected in a deposit of that character. That we have a true skeleton no one assumes; on the other hand, the regular spherical laminæ of figure 3 may in other specimens be quite irregularly undulating, as in figure 6, or practically straight, as in figure 5, lower part. To judge from the specimens figured, without taking into account the general view of the structures in

the rock, the only possible explanation other than that the structures are due to secondary "concretionary" changes in the sedimentary mass, is that we have here structures that might be compared to stromatolites and oolites—primary deposits, yet not of a character that would justify the introducing of generic and specific names. Yet there are fundamental differences between oolites and the specimens shown in figures 1 and 3, and between stromatolites and specimens like those in figures 2, 5, and 6. First among these differences is the great thickness of the laminæ when compared to the delicate laminations of oolites and stromatolites (the corresponding hot-spring and "sinter" calcareous deposits included); another is the very considerable dimensions of the spherical bodies here shown, a parallel to which is not known from recent deposits. In addition, we see that the spherical bodies often pass with their lamination into each other, as may very distinctly be seen in parts of the specimen depicted in figure 3, and even more so on the other side of the specimen. The spheres are parts of a large coherent mass. This feature contrasts decidedly with the ordinary oolitic structure, but is not infrequently seen in typical concretions, *e. g.*, in chert nodules where the laminæ may be arranged around different centers, yet the outer laminæ of one sphere pass into the corresponding ones of the neighboring spheres.

In the botryoidal concretions so common in the Fulwell quarries, we have great clusters of coherent spheres that suggest a somewhat similar mode of formation. A most important feature of difference is the existence of a sometimes extremely strongly marked radiating element in the Permian structures; a similar type of radiating rods is not known in stromatolites and oolites. When there is a radiating structure in oolites, it is due to crystal fibres, while the rods of the structures here figured are made up of fine-grained—sometimes extremely fine-grained—limestone. We may have tube-like structures in the stromatolites, indeed these are very typical, but these tubes are, when the rock is in an unchanged condition, not at all of a similar regular type.[11]

Thus, judging from the general characters of the speci-

[11] How a secondary chemical change of the rocks tends toward giving a more regular, geometrically arranged pattern is illustrated in the regularity of the silicified tubes in the stromatolite layer from the Alten district figured in my article on Finmarken of 1919 (p. 93), when compared with the figure on page 91 of the same paper whch shows the typical irregularly tubular stromatolite structure of an unaltered dolomite.

mens illustrated in this paper, we are brought to think of all these structures, as do the English geologists, as being formed secondarily by very important radical internal changes in the rocks. It has also been pointed out by several of these investigators—and I wish to emphasize this fact—that some of the characters of these structures suggest those developed by crystallization processes. Abbott (1900) points out the likeness of the "lines" and "planes" in the concretionary beds to the "lines which shoot across congealing water." I might mention especially that the regular right-angle relation between the direction of the concentric and vertical element of the structures seems to be of a similar character to the right-angle relation so commonly seen between the direction of the crystal fibres and the concentric laminæ in a laminated crystalline rock, taking as an example a piece of laminated, fibrous, crystalline aragonite like the one the structure of which is indicated in the lower drawing of figure 8, or the well known radiating fibres of calcite (or pyrite which by metasomatic change has taken the place of calcite) in an ordinary lime concretion.

That the changes in these rocks in general have been great can not well be doubted, and this fact is certainly proved by the English investigators. Yet it is in the residual material of a rock with a cellular structure similar to that which is so common in the Durham limestone that the extremely delicate chains of cells representing parts of blue-green algæ were observed. In sections of specimens of *Gallatinia pertexta*, a "species" which, as emphasized also by Walcott, is certainly very septaria-like, are reported minute remains of bacteria. This fact may not seem to harmonize very well with the idea of great internal changes in the rock, but we have only to consider how very delicate structures are often preserved in concretions of lime or of silica, where a transportation of mineral matter has also taken place, to realize that the secondary character of the rock and the occurrence of minute cells of plants are not mutually exclusive phenomena. The discovery of algæ and bacteria in pre-Cambrian strata, reported by Walcott, has therefore lost none of its importance, even if it should be found that these organisms are not responsible for the many curious structures found in the Algonkian Newland limestone.

University, Kristiania, October, 1920.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Perchloric Acid as a Dehydrating Agent in the Determination of Silica.*—H. H. Willard and W. E. Coke, of the University of Michigan, have found that the use of perchloric acid gives marked advantages over the usual methods for this very frequently required analytical determination. The dihydrate of perchloric acid, $HClO_4.2H_2O$, boils at 203°C, and at this temperature is a powerful dehydrating agent. Nearly all its salts are soluble in the strong acid and in water, presenting in this respect a great advantage over sulphuric acid for this purpose. The pure acid has been on the market for some time, and although still rather expensive it could be made more cheaply if there were sufficient demand for it.

The method as applied consists in dissolving the metal or silicate in hydrochloric or nitric acid, adding perchloric acid, or dissolving directly in perchloric acid, evaporating to dense fumes of the latter, boiling gently, in a covered beaker to avoid undue waste of the acid, for 15 or 20 minutes to dehydrate the silica, cooling and diluting with water. All salts are instantly soluble and the silica is filtered off and determined as usual. It contains less impurity than when separated by the usual methods. Moreover the silica remaining in solution is much less than in the usual method of evaporation to dryness and treatment with hydrochloric acid, so that except for the most accurate work it can be neglected. The operation is simple and rapid. Test analyses made by the authors upon very pure quartz sand (after fusion with sodium carbonate), upon cements, limestones, samples of willemite, irons, steels, aluminium and nickel gave very good results. It seems probable that this new method will find extensive application, both in scientific and technical analysis.—*Jour. Amer. Chem. Soc.*, **42**, 2208. H. L. W.

2. *The Chemistry and Crystallography of Some Fluorides of Cobalt, Nickel, Manganese and Copper.*—It is sometimes desirable, perhaps, to call attention to a chemical article for the purpose of showing that it is unsatisfactorily presented. Such appears to be the case in this article by Floyd H. Edmister and Hermon C. Cooper, which takes up about 15 pages of an important chemical journal. They have described the acid fluorides

$CoF_2.5HF.6H_2O$,
$NiF_2.5HF.6H_2O$,
$MnF_2 5HF.6H_2O$,
and $CuF_2.5HF.6H_2O$.

Upon reading this article one would suppose that these compounds were new ones, and of a new type. The authors refer to some work by Böhm in 1905 upon acid fluorides of cobalt, nickel and copper, and say, "The formulas assigned by Böhm to these fluorides are of a strongly acid type." Nothing further is said about Böhm's formulas, but upon consulting Böhm's article it appears that he described, besides others, the salts

$$CuF_2.5HF.5H_2O,$$
$$NiF_2.5HF.6H_2O,$$
$$\text{and } CoF_2.5HF.6H_2O,$$

two of which are identical with those of Edmister and Cooper, while the other one varies by only a single molecule of water. Böhm described also the crystalline form of all of these salts. There is no doubt that Edmister and Cooper should have mentioned Böhm's results.—*Jour. Amer. Chem. Soc.*, **42**, 2419.

H. L. W.

3. *Notes on Chemical Research*, by W. P. DREAPER. 12mo, pp. 195. Philadelphia, 1920 (P. Blakiston's Son & Co.).—This book from England now appears in a considerably enlarged second edition. It gives a general discussion of chemical investigations, and is intended particularly for the use of young chemists who are engaged or about to be engaged in industrial work. The book is an interesting one and it gives much useful information and advice. Many will not agree with the opinion of the author that a post-graduate course of research work in college is of doubtful advantage to the industrial research chemist, but very probably this opinion is the correct one in connection with most of the chemical manufactures in England. The view is expressed that it is seldom that a man can combine the experience and qualifications of a first-class chemist and of an engineer; hence the combination of the two professions in the "so-called chemical engineer" is not approved of.

H. L. W.

4. *Elementary Chemistry for Coal-mining Students;* by L. T. O'SHEA. 12mo, pp. 319. London, 1920 (Longmans, Green and Co. Price, New York, $3).—This book has been prepared for the use of a special class of students, for whom the ordinary text book of chemistry is not well adapted, since it contains much that is unnecessary for them to study, and since much that it is desirable for them to know is not found in it. It appears that the book is a very satisfactory one for its purpose. It presents clearly the fundamental principles of the science, it discusses particularly the elements occurring in coal, while special attention is paid to the explosive, suffocating and poisonous gases that may occur in coal mines. The chemistry and technology of coal and coke and the by-products are well presented, while the discussions of explosives and explosions of

gases and coal dust are particularly good. On account of its excellent special features the book should be of interest to many who are not directly connected with coal mining.

H. L. W.

5. *Creative Chemistry*, by EDWIN E. SLOSSON. 12mo, pp. 311. New York, 1920 (The Century Co.).—This book gives an account of recent achievements in the chemical industries in a popular and very forcible style. The subjects treated include explosives, artificial fertilizers, coal-tar colors, synthetic perfumes and flavors, cellulose, synthetic plastics, rubber, sugar, corn products, fats and oils, fumes for warfare, electric furnace products, and metals and alloys. There are many excellent illustrations, and an extensive list of references for reading is appended. The book is an excellent one for the general reader, and it appears to be well adapted to arouse the interest and increase the knowledge of chemical students. H. L. W.

6. *The Thermionic Vacuum Tube;* by H. J. VAN DER BIJL. Pp. xix, 391. New York 1920 (McGraw-Hill Book Co.).—No physical discovery or development of the last decade can compare in importance with the vacuum tube, which certainly ranks with the telephone, and possibly with the dynamo in its value to our social economy. It is the fruitage of the patient labors of two generations of scientists, and the principles of its operation cannot be comprehended in any engineering rule of thumb. The student who seeks to master its operation will have need of a thorough preparation in physics and mathematics.

The use of the vacuum tube was greatly stimulated by the war and while much that was then discovered has possibly not yet been released, the present treatise is easily the foremost presentation of its theory and applications which has yet appeared. Chapters I, II, III, and V treat of the nature of electrons, their release from bodies and the phenomena of ionization. Chapter IV details the characteristics of various tubes, a technical term meaning the functional relation between the variables of the tube. Chapter VI explains the use of the tube as a "valve" or rectifier. Chapter VII treats the three electrode tube or audion as amplifier. Chapter VIII is devoted to the tube as generator of electric oscillations. Chapter IX explains the modulation and detection of currents, and Chapter X discusses the function of the tube in a variety of other applications.

This exposition of the author carries especial weight because he occupied for some time the position of research physicist with the American Telephone and Telegraph Company and with The Western Electric Company. F. E. B.

7. *Où en est La Météorologie;* by ALPHONSE BERGET. Pp. vii, 300. Paris, 1920 (Gauthier-Villars et Cie).—This is one of a series of a dozen or more projected volumes (*Collection des Mises au Point*), aiming to give a compendious presentation of

the present attainment in various branches of science. It contains a general account of the composition of the atmosphere; a study of its various properties and phenomena and an explanation of the principles of weather prediction. It is obviously a book of information for the interested reader rather than a treatise for the more serious student. F. E. B.

8. *Etude sur Le Système Solaire;* by P. REYNAUD. Pp. xiv, 82. Paris, 1919 (Gauthier-Villars et Cie).—Volumes of observations upon physical and astronomical phenomena are added to our collections each year, but in spite of all the material little progress is being made in coordinating it and deducing the laws which govern the phenomena. The first statement of a law will usually appear in some empirical relation. There was a time when Kepler's Laws and Mendeleeff's Periodic Law were simply empirical. The former have now a sound dynamical basis, and the latter is fast developing from the theory of atomic structure. The study of Dr. Reynaud is a commendable attempt to discover whether any relation can be found to describe the location of the planets in the solar system and the disposition of the satellites about a planet. Bode's law, despite its successful prediction of the orbits of the asteroids and Uranus, could not survive its failure in the case of Neptune, and has been relegated to the mathematical curiosities. Reynaud considers that since the evolution of any planet and its satellites has followed the same laws as the evolution of the solar system there must be some analogy in the spacing of the members of the system, and he works out some rather striking relations or at least coincidences. By arranging the planets in two groups, between which the asteroids form the dividing line, it may be seen that the distances from the sun in the first group fall approximately into the suite 1, 2, 4, 6, 8 while those of the second have 30 times the same numbers except that the place 1 is vacant in the first series and the place 30×8 in the second, or we may assign to these places the hypothetical planets Vulcan and Pluto. Now by introducing $L = 26.25$ million kilometers, the lower limit for any possible planet, and $D = 1.41$ the specific gravity of the sun, our author finds that the distance of any planet may be expressed by a formula of the form $L D^m$ where m takes on integral values. The success of such a formulation may best be judged by the following table in which the distances are in million kilometers:

Calculated			*Observed*		
26.25×1.41	=	37.0	Vulcan		?
$26.25 \times (1.41)^2$	=	52.2	Mercury perihelion		46.0
$26.25 \times (1.41)^4$	=	104	Venus	"	107
$26.25 \times (1.41)^5$	=	146	Earth	"	147
$26.25 \times (1.41)^6$	=	206	Mars	"	206
$26.25 \times (1.41)^8$	=	410	Asteroids		411

$26.25 \times (1.41)^{10} = 815$	Jupiter	aphelion	815
$26.25 \times (1.41)^{12} = 1621$	Saturn	"	1508
$26.25 \times (1.41)^{14} = 3222$	Uranus	"	3006
$26.25 \times (1.41)^{15} = 4543$	Neptune	"	4542
$26.25 \times (1.41)^{16} = 6407$	Pluto		?

The perihelion distances have been quoted for the inferior planets and the aphelion distances for the superior, on the assumption that since the mass of Jupiter so far exceeds that of any other planet it would influence the distances in these directions.

If it is surprising that this relation fits the planetary distances so well, it is not less so that the author is able to apply a similar formula to the satellites of Jupiter, Saturn, and Uranus with nearly the same success. As he remarks, "if this law had been established in 1891 it would have been possible to have predicted with a high degree of precision the position of the 5th, 7th, 8th, and 9th Satellites of Jupiter." Fulfillment of prediction would have given great weight to a hypothetical law, and it is a field that is still open for there are several vacant places in Reynaud's tables. He has also developed curious relations between the densities, the rotations and the inferior limit of satellites but whether his formula is an approximate representation of the progressive condensation of the solar nebula or not, can hardly be answered until we have a better dynamical theory of the evolution of a planetary system. F. E. B.

9. *The National Physical Laboratory; Report for the Year 1919.* Pp. 151 with 37 figures. London 1920 (His Majesty's Stationery Office).—A perusal of this report will leave the impression that not all the consequences of the war are malign. That critical period set on foot a great train of investigations in the domain of physics, many of which promise a fruitful harvest for the arts of peace. It is not possible to present any resumé of such a report, but opening it casually one may find illustrations of the kind of thing just mentioned.

P. 35. A catalytic lamp in which the combustion of gasoline proceeds without the production of flame. The products of combustion and the hot air may be utilized on aeromotor- or other engines as such lamps may be inserted under the hood without danger of fire.

P. 60. The invention of a soft valve containing a silver anode amalgamated with mercury. When used as a receiver for loud wireless signals the illumination of the vapor due to collisions makes it possible to read signals by visual observation of the tube.

P. 126. A successful study has been made of the alloys of aluminum with copper and zinc, with iron and silicon, and with magnesium and silicon. Tests have been made of their fitness for general castings; for working parts at high temperatures, e. g. pistons of aero-engines; for wrought material for

the structural parts of aeroplanes; for very thin sheets to serve as a strong and non-inflammable covering for aeroplane wings.

A considerable section of the report is devoted to gauge testing by means of optical projectors. F. E. B.

II. Geology and Mineralogy.

1. *The Geology of Anglesey;* by Edward Greenly. Vols. I and II, pp. 980, with 60 plates in the text, 17 folding plates, and 346 text figures. Memoir of the Geological Survey of Great Britain, 1919.—These two handsome volumes, excellently illustrated and well bound, embody the results of the author's work on the geology of Anglesey during a period of twenty-four years. Greenly resigned from the Geological Survey in 1895, but, within a few weeks after his resignation, he began a detailed study of Anglesey, being irresistibly drawn to this task by the fascination of the crystalline schists. In appreciative recognition of his work the Geological Society of London has lately awarded him the Lyell medal.

Volume I deals with the Mona Complex, as the metamorphic rocks of Anglesey are termed. They have long been of chief interest in the geology of the island. They embrace an area of 200 square miles and are by far the largest area of metamorphic rocks in southern Britain. They are of Pre-Cambrian age and are 20,000 feet thick, exclusive of the gneisses upon which the other members of the Complex are supposed to lie unconformably. The Mona Complex lends itself particularly well to a study of the relation of the degree of metamorphism to the tectonics. The author has been able to recognize three different successions in the Complex: a stratigraphic, a tectonic, and a metamorphic. The rocks have been folded into three master primary recumbent folds, the horizontal amplitude of which is as much as 60 miles. Superimposed on the primary folds are secondary and subordinate folds, probably due to the same dynamic impulse that produced the major folding. The regional metamorphism of the Mona Complex is of dynamic origin, and is ascribed to the superimposed foldings. The three primary recumbent folds, piled one on the other, constitute three tectonic horizons, within each of which the intensity of metamorphism progressively decreases upward. Thus, a waxing and waning of metamorphism is repeated thrice hypsometrically. The author explains this remarkable sequence by the fact that although metamorphism is a function of depth, it is a function of the thickness of the cover that was present at the time it was developing, not of the cover that may have been imposed after it had developed. Metamorphism may develop in a higher fold without appreciably intensifying the crystalline condition of a subjacent fold. For the conversion of the energy of folding into the molecular energy necessary to effect metamorphism can take place only at the actual locus of folding, and the underlying fold was therefore metamorphically inert, dead, when the next recumbent fold was rolled

Volume II deals mainly with the rocks younger than the Mona Complex. The Ordovician rocks are the next most important after those of the Complex. They are described in detail, as are also the later Paleozoic rocks, the Pleistocene glaciation, the origin of the land forms, and the economic resources. Under the latter is described, so far as present conditions allow, the old copper mine of Parys Mountain, once the most productive copper mine of Europe, which still yields annually a modest amount of copper, obtained, however, from the cupriferous waters that flow from the old, caved-in workings. ADOLPH KNOPF.

2. *Abriss der Allgemeinen und Stratigraphischen Geologie;* by EMANUEL KAYSER. 2d revised edition. Pp. viii, 460, 212 text figs., 54 plates of fossils, 1 large geologic map, Stuttgart (Ferdinand Enke), 1920.—Professor Kayser, formerly of the University of Marburg, and now at Munich, is the author of the widely used "Allgemeine Geologie," and "Geologische Formationskunde." These books have become too detailed for undergraduates, and in the present "Abriss," now in its second edition, he has presented the earth sciences for this class of students. Less than one-half of the text (195 pages) is devoted to physical geology, while the greater part (224 pages) deals with historical geology. We see therefore that in Germany historical geology is held to be equally as important as dynamic and structural geology, a viewpoint far less popular in this country. The book has an excellent geologic map of central Europe, and is a good volume for American teachers to have on their shelves. C. S.

3. *The Geology and Mineral Resources of Bexar County;* by E. H. SELLARDS. Univ. of Texas Bull., No. **1932**, pp. 169, 1 pl., 1 map, 6 text figs., 1919 (1920).—This report treats at length of the geologic and economic resources of the Lower and Upper Cretaceous and Cenozoic formations, having together a thickness of over 4,800 feet. They rest upon ancient schists. The outcrops of the formations are mapped. C. S.

4. *The Geology of Tarrant County;* by W. M. WINTON and W. S. ADKINS. Univ. of Texas Bull., No. **1931**, pp. 122, 6 pls., 2 maps, 6 text figs., 1919 (1920).—Here is described and mapped the geology of the Fort Worth area, the surface strata being in the main of the Lower Cretaceous. The various formations are discussed in considerable detail, with lists of their characteristic fossils. C. S.

5. *Mineralogy: an Introduction to the Study of Minerals and Crystals;* by E. H. KRAUS and W. F. HUNT. Pp. 561, 696 figs. in the text. McGraw-Hill Book Co., 1920.—This latest addition to the list of elementary mineralogies has many features that will commend it to the instructor of mineralogy. It covers all the different branches of the field, is concise and well written, and on the whole is unusually well illustrated. A novel and attractive feature is the inclusion of a number of photographs of eminent mineralogists with added brief biographical statements. These serve to give an historical perspective to the subject that is as pleasing as it is unusual.

It is to be questioned if it is worth while to include in an elementary book a brief and therefore necessarily unsatisfactory treatment of the difficult subject of the optical properties of crystals. The determinative tables which are based upon the physical properties of minerals seem to be unnecessarily bulky and consequently difficult to use. W. E. F.

6. *The Ore Deposits of Utah;* by B. S. BUTLER, G. F. LOUGHLIN, V. C. HEIKES and Others. U. S. Geol. Surv., Prof. Paper **111**, 1920. Pp. 672, 74 figs., 57 pls.—This is the second professional paper to appear detailing the geology and ore deposits of a single state. In 1910 a similar report on New Mexico was published and reports dealing with other states are in preparation. While a large part of the material in the present volume has been previously published in other reports, the gathering of it together in a condensed form into a single volume and including with it a general study of the ore deposits of the state makes it a most valuable addition to the literature of economic geology. From this study of the state as a whole has come the following important generalization.

The value of an ore deposit found in connection with an igneous stock will be largely determined by the amount of erosion the stock has undergone. Deposits around the apex of stocks are larger and more valuable than those located at greater depths in and around the stock. Consequently stocks that have been least eroded will be more favorable as locations of ore deposits. The amount of erosion of a given stock can be estimated from the chemical character of the igneous rocks exposed. The lower portion of the stock is uniformly more siliceous, the character of the rock changing from monzonite and diorite at the apex to granodiorite and granite at greater depths. W. E. F.

OBITUARY.

DR. HENRY A. BUMSTEAD, professor of physics and director of the Sloane Physical Laboratory at Yale University, and for the past half-year on leave from the University as Chairman of the National Research Council of Washington, D. C., died suddenly on the train on the night of December 31 while returning to Washington from Chicago. A notice is deferred until a later number.

SIR WILLIAM DE WIVELESLIE ABNEY, the gifted English astronomer, died on December 2 at the age of seventy-seven years.

PERCIVAL SPENCER UMFREVILLE died at Harpenden, England, at the age of sixty-two years. His chief work was in physical chemistry, dealing with the phenomena concerned in the formation and solution of salts.

WILLIAM ARTHUR HOWARD, research fellow in the Imperial College of Science and Technology, died suddenly as the result of a laboratory accident on December 6 at the age of twenty-six years.

DR. YVES DELAGE, professor of zoology in the University of ·ris, died recently at the age of sixty-six years.

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

ART. XIV.—*John Day Promerycochœri, with Descriptions of Five New Species and One New Subgenus*; by MALCOLM RUTHERFORD THORPE.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

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INTRODUCTION.

One of the most remarkable features of the specimens of the John Day genus *Promerycochœrus* in the Marsh Collection is the unusual variation shown in the tooth structure. Styles are developed on the molar teeth, both from the cingulum and from the cone itself, with such frequency that they become of no value for specific determinations. The metastyles of M^3 exhibit great variation in size and in robustness, as well as in the degree of inward rotation. Likewise, there is variation in the proportions of size between the superior molars in different individuals. It is interesting to note in this connection that the paratype of *Merycochœrus proprius* Leidy[1] has

[1] Joseph Leidy, Jour. Acad. Nat. Sci., Philadelphia (2), 7, 110, 380, pl. 10, fig. 5, 1869. This paratype is No. 445, U. S. National Museum, and was found near Ft. Laramie, Wyo.

a small style developed from the hypocone, of which it is an integral part.

There is also great variation in the size, shape, and curvature of the zygomatic process, including the malar below the orbit. These variations do not correlate with the size of the canine, and do not appear to be a sexual character, as Scott[2] pointed out, and as studies of the present material likewise show. The development of the zygoma in this group is so remarkable as well as unusual that it must possess considerable significance. The chief function was apparently to furnish sufficient surface for attachment for the powerful muscles necessary in the mastication of the coarse food upon which these animals subsisted. It has been suggested that these processes may indicate the presence of some external embellishment, as for example, the excrescences on the African wart-hog.

There is likewise a very marked variation in the various skull elements, while the various parts of the skeleton have changed but very little, except in size, from those of the earlier Eporeodons. This variation is due, probably, to some external causes which are reflected in the skull, where the greatest evolution is localized in all of the genera of the Oreodontidæ (Merycoidodontidæ). The John Day representatives of the genus *Promerycochœrus* became extinct, so far as now known, with the close of the Oligocene. To what causes these variations and extinction are due, is not clear. Possibly a changing climate with its concomitant floral changes was responsible, or a different environment caused by the former habitat becoming uninhabitable through the influx of poisonous gases, or ash falls occurring with sufficient frequency and volume to render the area barren and devoid of life. Racial old age or emigration may have been contributing factors. The chief consideration is that this group of large animals became extinct and that, before extinction, they had begun to vary to a great degree. Many other groups also became extinct in this basin with the end of Oligocene times, such as *Eporeodon, Agriochœrus, Mesohippus, Protapirus, Elotherium,* and many of the carnivores and rodents.

In connection with the present study of *Promerycochœrus,* the writer wishes to express his appreciation of the courtesy shown him by Messrs. Matthew and Granger,

[2] W. B. Scott, Trans. Amer. Philos. Soc., **17**, 151, 1893.

of the American Museum of Natural History, in allowing him to measure and study the Cope types of this genus. The illustrations of the new species were made by Mr. Rudolf Weber.

Geological Sketch.

In view of the fact that the specimens of fossil vertebrates in the Marsh Collection, from the John Day formation, obtained approximately fifty years ago, are now being intensively studied and described, it is interesting to note that Professor Marsh wrote the earliest general discussion of the geology of this basin of deposition, and that he first proposed the name, John Day, for these deposits. This name has become firmly established in geologic nomenclature in spite of the many substitutes which have been proposed.

In 1875,[3] Marsh wrote:

"The Blue Mountains formed the eastern and southern shores of this lake, but its other limits are difficult to ascertain, as this whole country has since been deeply buried by successive outflows of volcanic rocks. It is only where the latter have been washed away that the lake deposits can be examined. The discovery and first explorations in this basin were made by Rev. Thomas Condon, the present state geologist of Oregon. The typical localities of this Miocene basin are along the John Day River, and this name may very properly be used to designate the lake-basin. The strata in this basin are more or less inclined, and of great thickness. One section, near the John Day River, examined by the writer in 1871, and again in 1873, seems to indicate a thickness of not less than 5,000 feet. The upper beds alone of this series correspond to the deposits in the White River basin. The lower portion also is clearly Miocene, as shown by its vertebrate fauna, which differs in many respects from that above. Beneath these strata are seen, at a few localities, the Eocene beds containing fossil plants, mentioned above. They are more highly inclined than the Miocene beds, and some of them show that they have been subjected to heat. The inferior strata elsewhere are Mesozoic, and apparently Cretaceous. Above the Miocene strata, Pliocene beds are seen in a few places, but the basalt covers nearly all."

This basalt is the Columbia lava flow which delimits the upward range of the John Day. The estimate of 5,000 feet, made above, seems somewhat excessive, although southerly at Logan Butte the strata exceed

[3] O. C. Marsh, this Journal (2), 9, 52.

4,000 feet, while north of the mountains in the fossil localities, Merriam[4] considers that the John Day does not exceed a thickness of much over 2,000 feet.

The John Day formation is divided into three levels, designated as lower, middle, and upper. Paleontologically, the lower has no designation, but the middle is termed the *Diceratherium* zone (Wortman), and the upper the *Promerycochœrus* zone (formerly *Merycochœrus*). The writer considers the designation of the middle zone a misnomer.

Lower John Day.—This division of the John Day is practically barren of fossils. It lies unconformably[5] upon the Upper Eocene Clarno formation, and consists of red, white, and green tufaceous shales. Collier,[6] however, says it overlies the Clarno "with apparent conformity." This division is between 200 and 300 feet thick and the shale is soft and easily eroded. The characteristic erosion topography consists of low rounded mud-covered domes. Collier[7] considers these beds of possible Eocene age, to be regarded as part of the Clarno.

Middle John Day.—This division is characterized by drab and bluish green andesitic tuffs, ranging in thickness from 500 feet at Turtle Cove to 1,000 feet at Bridge Creek. Thin rhyolitic flows are interbedded in the strata. Erosion sometimes produces rounded hills, but more often steep pinnacles and cliffs. Layers of nodules are common and characteristic, in contrast to both the lower and upper divisions. This middle division has furnished the greater number of fossils. The structure shows some tilting and deformation of the strata but not to as great a degree as the lower division.

Upper John Day.—The upper John Day, 300 to 400 feet thick, is composed chiefly of buff colored tuffs or ash deposits, often overlain by sand and gravels at the top. Erosion produces steep cliffs and bluffs.

At Bridge Creek and Turtle Cove the whole section of the John Day is exposed, while at Clarno the lower and middle beds are well shown. Along Haystack Valley, chiefly upper, but some middle strata are exposed. The

[4] J. C. Merriam, Univ. Calif., Bull. Dept. Geology, vol. 2, 293, 1901.

[5] J. C. Merriam and W. J. Sinclair, Univ. Calif., Bull. Dept. Geology, vol. 5, 173, 1907.

[6] A. J. Collier, Min. Res. of Oregon, Oregon Bur. Mines and Geology, 1, 13, 1914.

[7] Op. cit., p. 14.

lower division is apparently the most disturbed, while the middle and upper are but slightly folded, faulted, and tilted in different localities. The mode of deposition of the John Day is still an open question, but in general, the sediments were probably laid down chiefly by æolian, but partly by fluviatile agencies, and not wholly by lacustrine as many writers formerly supposed. Whether the ash was poured out in great volume from neighboring vents or whether it was gradually blown into the atmosphere can not be definitely decided at present. If the former, it must have caused the death of great numbers of individuals, and the fact that many specimens of *Eporeodon* and *Promerycochœrus* with milk dentition are represented in the collection may have some bearing on the question, which further studies may help to solve.

The geology of the North Fork of the John Day River is but little known, although it is one of the critical areas of this basin. Geologically, it is important as showing a divergence from the typical John Day formation as elsewhere exposed, in that it exhibits red beds at or near the top. At all other localities in this area, the red beds are apparently confined to the lower John Day. At least one fossil horizon is dark chocolate in color of matrix. Other geologic peculiarities exist in this locality, which are not pertinent to so brief a discussion as this one. On the whole, these beds are probably mainly upper John Day with perhaps some exposures of the middle. Paleontologically, the North Fork fauna is different from that of the rest of the basin. Two of the new species herein described were found in this area. Cope indicated this faunal distinction in 1884, and the material of other groups in the Marsh Collection, in so far as it has been worked up and studied, points to the same conclusion. For the present it will be necessary to forego any positive statements regarding either the age or the geologic sequence of this locality, but it is evident that the geology and fauna are both largely distinct in the North Fork region from those of the rest of the basin.

Geographic Distribution of Species.

The majority of the specimens of *Promerycochœrus* in the Marsh Collection bear accurate field labels, but there are a few of doubtful locality, although from the matrix, and from the letters of the field men, which state where

they were collecting at definite periods, this doubt seems very nearly to vanish. The geographic distribution of the various species may be tabulated as follows:

	Bridge Creek	Turtle Cove	Haystack Valley	Clarno Bottom	N. Fork John Day River†
P. superbus	20 + 7*	3 + 2			? 1
P. leidyi	2 + 1	1 + 1	1	1	
P. macrostegus	3	1 + 2	1 + 3		
P. inflatus, n. sp.........	1				
P. chelydra		0 + 1	1 + 1		
P. lulli, n. sp.		1			
P. microcephalus, n. sp...		0 + 1			
P. marshi, n. sp.........			1		
P. latidens, n. sp.					1
Desmatochœrus curvidens, subgen. et sp. nov......					1

* The second figure refers to specimens of doubtful locality.
† Fifteen miles above junction with main stream.

Up to the present, it has been considered that *Promerycochœrus* was limited to the upper John Day, but if it is assumed that the green matrix is confined to the middle, and the gray and buff to the upper horizon, then, using 70 specimens in this collection as a basis, it is found that approximately 14 per cent were collected in green strata and hence belong to the middle John Day. The remainder, 86 per cent, were enclosed in gray or buff matrix, with the exception of two specimens showing brown country rock. The species having representatives formerly enclosed in matrix bearing an undoubted green color are as follows: *P. leidyi*, 1; *P. macrostegus*, 3; *P. superbus*, 3; *P. lulli*, 1; *P. microcephalus*, 1; and *Desmatochœrus curvidens*, 1.

In regard to individual age, again using these 70 specimens as a basis, 11.5 per cent have milk dentition, 73 per cent are fully adult and about middle-aged, while 11 per cent are post-mature and the remainder very old.

Description of Species.

Promerycochœrus superbus (Leidy).

Synonyms: *Oreodon superbus* Leidy, Proc. Acad. Nat. Sci. Phila., **22**, 111-112, 1870; *Eporeodon superbus* Marsh, this Jour. (3), **9**, 250, 1875; *Eucrotaphus superbus* Cope, Bull. U. S. Geol.

Surv. Terr., vol. 5, 59, 1880; *Merycochœrus superbus* Cope, Proc. Amer. Philos. Soc., **21**, 521-523, 1884; ***Promerycochœrus superbus*** Douglass, this Jour. (4), **11**, 82, 1901; ***Paracotylops superbus*** Matthew in Merriam, Univ. Calif., Bull. Dept. Geology, vol. **2**, 296, 1901; *Merycochœrus temporalis* Bettany, Quart. Jour. Geol. Soc., London, **32**, 269-272, pl. 17, 1876.

Cotypes: No. 516, Condon Collection, Univ. of Oregon; Cat. Nos. 10151, 10152, 10153, 10967, 10968, Y. P. M. All from Upper Oligocene (upper John Day), Bridge Creek, John Day River, Oregon.

History.—Since this species has been subjected to so many changes in its classification, it is pertinent briefly to review its history. The attention of paleontologists was first directed to Oregon in 1870, when Leidy reported on a collection of vertebrate fossils sent to the Smithsonian Institution by the Rev. Thomas Condon, of Dalles City, Oregon. These fossils were collected by Mr. Condon in the valley of Bridge Creek, John Day River, Oregon. Most of these specimens belonged, Leidy said,

"apparently to a species of *Oreodon*, larger than any previously discovered and equalling in size *Merycochœrus proprius.* Indeed, so far as we are familiar with the skull of both, the two are so nearly alike that one may be regarded as only a variety of the other, or at most both may be viewed as distinct species of the same genus. I am, however, disposed to view one as the offspring, by selection, of the other, and regard them as corresponding species of two genera which existed in different times or localities."

The characters of the species, as outlined in this report, are as follows: Form and constitution of cranium same as in *Oreodon culbertsonii;* large inflated bullæ; face rather more abruptly narrowed in advance of the orbits than in *Oreodon major*, but not to the same degree as in *Merycochœrus proprius;* infra-orbital arch $1\frac{1}{2}$ inches deep; orbits small; lacrymal fossa shallow, as in *Oreodon gracilis;* infra-orbital foramen above P^4; jaws not so robust as in *M. proprius*, and bone less thick; length of skull, 14 inches; crown of inferior canine (P_1) one inch wide antero-posteriorly, and the three succeeding premolars occupy 2 1/3 inches.

In 1871,[8] Leidy briefly re-described this species, adding that the canines and premolars are proportionately wider and thinner than in the Badlands *Oreodon.* Up to 1873, there had been no published illustrations of the species,

[8] Joseph Leidy, 2d (4th) Ann. Rept., U. S. Geol. Survey Terr., 346-347.

but during the year Leidy's "Contributions to the Extinct Vertebrate Fauna of the Western Territories" was issued, which contained a lateral view of the skull, and tooth, jaw, and skull parts. In this reference Leidy notes that "in most of the specimens the temporal surface slopes from the sagittal crest with a slight sigmoid curve"; the course of the squamous suture is followed by a pair of grooves, one in front and the other behind, the former being the more prominent. The bullæ are ovoidal, with the antero-posterior diameter the greater, and they extend from the paramastoid process to the middle line of the glenoid articular surface, and project below it for half their length..

Marsh placed this species under the genus *Eporeodon,* which he established in 1875. He based this classification on the presence of large bullæ and on the large size of the animal. The name was again changed in 1879 by Cope, who placed it under *Eucrotaphus,* without stating his reasons therefor, while in 1884 he placed it under the genus *Merycochœrus* Leidy. In his key to the species, he laid emphasis on the position of the infra-orbital foramen; expansion of the posterior part of the zygoma; moderate posterior production of the palate; head elongated; and otic bullæ large and compressed. Douglass was the first to propose a division of the forms of *Merycochœrus.* He referred *M. leidyi, chelydra, macrostegus,* and *montanus* to the new genus *Promerycochœrus,* which he proposed, with *P. superbus* (Leidy) as the type; while he left *M. proprius, rusticus, laticeps, compressidens, altiramus,* and *madisonius* under *Merycochœrus.* Matthew had also definitely determined that many forms, not similar to the type of *Merycochœrus,* had been placed in that genus. He proposed to refer some of the species to a new genus, *Paracotylops,* with *P. superbus* (Leidy) as the type.

Additional characters.—From the many specimens in the Marsh Collection, it is possible to expand the knowledge of this species. The superior molars are internally surrounded by a well developed cingulum. The metastyle is large and robust. It forms an abrupt angle with the hypocone and is situated almost in an antero-posterior line with the paracone. The premolars are normally spaced, as are the incisors. The incisive foramina are roughly right-triangular, with the apex posteriorly di-

rected, and the longest leg lying close to and parallel with the sagittal plane. The inferior view shows a rather abrupt anterior termination of the malar portion of the zygoma above the middle of M^2. The basicranial axis is not steep. The bullæ are large, ovoidal, and extend downward below the glenoid tubercles, which are compressed antero-posteriorly and stout.

The basicranial foramina resemble those of *Eporeodon*, rather than *Oreodon* (*Merycoidodon*). The condylar foramen is normal and separated from the foramen lacerum posterius by a ridge from the paroccipital process. This latter foramen is relatively much larger than in *Oreodon* (*Merycoidodon*). The foramen lacerum medium is also large and occupies a position corresponding to that in *Eporeodon*. The foramen ovale is large and oval-shaped. It is located much farther anteriorly to the bullæ than in *Oreodon* (*Merycoidodon*). But one specimen, No. 10154, of this collection shows a foramen rotundum, and in this one it is so small that it could not have been functional, and I consider it justifiable to consider that this foramen is not present in the John Day Promerycochœri, any more than it is in *Eporeodon*. The paramastoid processes are broad and plate-like. The canine is flat posteriorly and rounded anteriorly, but that of *P. macrostegus* is more oblong-square, with the long diameter transverse to the sagittal plane.

The orbits are nearly round. The lacrymal fossæ are usually very shallow and wide, although confined to the lacrymal bone. This is, however, subject to slight variation. The malar beneath the orbit is very nearly flat, while beneath the lacrymal fossa it is concave and then convex from above downward. The depth below the orbit varies from 35 to 43 mm. The anterior ridge of the zygoma is prolonged forward and upward in the maxillary beyond the infra-orbital foramen, which is above P^4. The posterior or squamous portion of the zygoma does not rise as high as the sagittal crest, and its general form, including the postorbital bridge, is that of a fairly wide U. The external edge is not so heavy nor so rugose as is that of *P. macrostegus*. The superior surface of the skull slopes more steeply from the sagittal crest than in the latter species. The posterior half of the lacrymal fossa is sometimes quite rugose; the anterior very smooth. The nasals extend up to a point on the sagittal

plane slightly behind the anterior orbital margins. The supra-orbital grooves are well marked. The frontals are roughly diamond-shaped. The nasals are prolonged to a point nearly above the incisors. From the palate to the top of the nasal ridge at the third premolar is 62 mm. measured in the sagittal plane, and the height from the posterior nares to the frontal measured in the same plane at right angles to the palate is 83 mm. The transverse crests are farther apart than in *P. macrostegus.* No. 10978 has partly milk dentition which, in part, shows the order of succession of permanent dentition to be M^1, M^2, M^3, P^4, P^3, and P^2. P^1, C, and the incisors are broken away so that the determination of their order can not be made from the specimen. The mandible is of about uniform depth beneath the tooth-row. The postero-inferior part of the symphysis lies below the interval between P_2 and P_3. These premolars are slightly crowded and placed obliquely. The mental foramen below P_2 is very large, while the one beneath the interval between P_3 and P_4 is comparatively small. The maximum length of the ramus is 231 mm. The masseteric fossa is deep and its inferior border does not extend below a posterior prolongation of the alveolar border. The sacrum of No. 10991 consists of three ankylosed vertebræ with parts of both ilia attached. The fourth sacral was formerly present. The length of the ankylosed vertebræ is 82 mm., and the transverse diameter of sacral I is 124 mm. The dorsal spines are not large. The maximum length of the centra of the last lumbar is 35 mm., while the transverse processes are about the same length. The height of the neural canal is 18 mm. No. 10989 consists in part of a nearly complete left ilium, acetabulum, and ischium, with a right acetabulum, and part of the pubis. This pelvis does not differ in essential respects from that of the John Day *Eporeodon,* except in size. The length from the anterior margin of the acetabulum to the end of the ilium is approximately 132 mm. The diameter of the acetabulum is 40 mm. The maximum diameter across the pelvis, measured from the external edges at the acetabuli, is approximately 157 mm. The pubic symphysis is not less than 60 mm., and may have been somewhat more. The length of the ischium is 79 mm., exclusive of the tip. This pelvis belonged to an old adult. No. 10983 has accessory styles on M^3. The left style is an integral

part of the hypocone, termed an hypostyle, whereas the right style is developed from the cingulum alone. Both have an average diameter of over 5 mm.

In the list of synonyms, *Merycochœrus temporalis* Bettany is intentionally placed at the end, partly not to break the continuity of the *P. superbus* series, and partly because it was considered as a distinct species until Cope wrote in 1884: "I cannot detect any difference between the specimen described by Mr. Bettany as the type of his *M. temporalis,* and those of the *M. superbus* in my possession." There are some minor differences between the type of this species and *P. superbus,* but they are too unimportant, in the writer's opinion, to consider of specific value, especially when this group shows so much variation. It would be exceedingly difficult to find any two specimens in the group between which many minor differences, at least, could not be detected.

Promerycochœrus chelydra (Cope).

Holotype, Cat. No. 7430, Cope Collection, A. M. N. H. Upper Oligocene (upper John Day), Bridge Creek, John Day River, Oregon. Figured by Peterson, Ann. Carnegie Mus., **9**, pl. 41, figs. 1, 2; pl. 42, fig. 1, 1914.

Specific characters.—Maximum width of skull anterior to glenoid articular surface, and equal to distance from paroccipital process to canine; posterior angle of zygoma rises nearly to level of sagittal crest; bullæ do not extend anterior to postglenoid processes; palate moderately produced; supra-occipital bone presents a wide, flat convexity above foramen magnum; superior molars lack an internal cingulum; bullæ normally small and subconical; infra-orbital foramen above P^4.

Two skulls in the Marsh Collection, Nos. 10962 and 10979, show the characters of this species quite well. In general proportions and appearance they differ not a great deal from *P. superbus,* except in the much greater bizygomatic diameter of the former. The internal cingulum is discontinuous, but is especially well developed on the posterior side of the protocones of M^2. The metastyle occupies the same relative position as in *P. superbus.*

Cope[9] wrote that "a line drawn through the postglenoid and paroccipital processes makes an angle of 90° with the

[9] Proc. Amer. Philos. Soc., 21, 523, 1884.

middle line, as in *M. superbus.*" This statement is in error, and should read 60°, the angle of both *P. superbus* and *P. chelydra.* The lacrymal fossa is well marked, but not deep. The orbits are more oblique than in *P. superbus,* and their vertical diameter exceeds the transverse. The malar is wide and flat. The squamous part of the zygoma is very heavy and massive, and the inferior surface as wide as in any John Day form in the genus. In our specimens the bullæ are slightly larger than in the type, extending to, but not below, the inferior surface of the postglenoid tubercle. This latter process has nearly the same transverse as antero-posterior dimension, with the former slightly the greater. The incisive foramina are large and approach close to the base of the canines. These foramina are wider than long, in which they differ from those in both *P. superbus* and *P. macrostegus.* The sagittal crest is thick and high.

Measurements of Holotype.

	mm.
Total length of skull, approx.	342
Bipostglenoid diameter	127
Bizygomatic diameter	250
Length of superior molar series	70
Length of superior premolar series	62
Length of superior dental series, inc. canine	157
Depth of malar below middle of orbit	36
Max. width of cranium	82
Diameter of postorbital constriction	59
Max. height of zygoma above glenoid surface	85
Width of frontals above middle of orbits	94.5
Width of face at infra-orbital foramina	70

Promerycochœrus macrostegus (Cope).

Holotype, Cat. No. 7444, Cope Collection, A. M. N. H. Upper Oligocene (upper John Day), Bridge Creek, John Day River, Oregon. Supplementary data from Cat. Nos. 10955 and 10957, Y. P. M. Figured by Scott, Morph. Jahrb., **16**, pl. 14, figs. 8, 9, 1890.

Specific characters.—Infra-orbital foramen above interval between M^1 and P^4; squamous part of zygoma much expanded, edge truncated; malar robust; palate much produced posteriorly; width of skull equal to length from condyles to P^4; maxillary produced anteriorly; frontal plane transverse, diamond-shaped; bullæ small, conical,

and delimited between anterior and posterior borders of postglenoid process; lacrymal fossa small but well developed; orbits very high; skull longer than *P. superbus*; very strong convexity above foramen magnum.

This species is not so robust as either *P. chelydra* or *P. latidens*. The face is strongly convex above the infra-orbital foramen, due to an upward-sloping ridge from the anterior zygomatic pedicle to the nasals. The orbits are directed but very slightly upward. The orbit is deeper than wide. The posterior part of the zygoma rises to the plane of the summit of the sagittal crest, which is not true of any other species. Its apex is above the external base of the postglenoid process. The prominence of the ridge along the parieto-squamosal suture is very variable, although it is a constant feature in all genera of the Oreodontidæ (Merycoidodontidæ). The marked convexity above the foramen magnum is separated from the posterior temporal angles by well defined lateral fossæ, which, however, are much smaller and less deep than in *P. latidens*. The mastoid and paroccipital processes do not close the auricular fossa below, but do approach close to the postglenoid tubercle, which is wide and robust and its height and thickness are equal. The bullæ are the smallest known in the genus. The palate is concave between the first true molars, while it is flat between the premolars. The infra-orbital foramen is large. The incisive foramina are large and oval-shaped, whereas in *P. chelydra* they are triangular.

The inferior edge of the ramus is straight below the tooth-row, except for the symphysial tuberosity, which, instead of being an individual peculiarity as Cope suggested, is found in all of the species of this genus. It is, however, subject to much variation in its development. The coronoid process is small and everted. The anterior inner edge encloses an elongate, well defined fossa. The masseteric fossa in the type is fairly shallow, although this appears to be a variable character. The premolars are large and the first three are two-rooted, while P^1 is separated by a marked diastema on either side, the greater being between it and the canine. The molars lack the internal cingula. P_2 is rudimental in that it has a prominent internal vertical ridge. The true canine is very wide. The incisive alveolar border overhangs a symphysial concavity. The lower incisors are crowded and overlap each other and the true canine.

Measurements of Holotype.

	mm.
Total length of skull, approx.	380
Bipostglenoid diameter	133
Bizygomatic diameter	246
Length of superior molar series	81
Length of superior premolar series	90.5
Length of superior dental series, inc. canine	179.5
Depth of malar below middle of orbit	38.5
Max. width of cranium	94
Diameter of postorbital constriction	62.4
Max. height of zygoma above glenoid surface	71
Width of frontals above middle of orbit	110.6
Width of face at infra-orbital foramina	85
Length of inferior molar series	86.5
Length of inferior premolar series	77.5
Depth of ramus from condyle to angle	133
Length of ramus from condyle to angle	276

Promerycochœrus leidyi (Bettany).

Holotype in Woodwardian Museum, Cambridge. Upper Oligocene (upper John Day), Bridge Creek, John Day River, Oregon. Figured by Bettany, Quart. Jour. Geol. Soc., London, **32,** pl. 18, 1876.

Specific characters.—Lacrymal fossa conical and deep; prominent lacrymal tubercle on anterior orbital margin; infra-orbital arch slightly deeper than in *P. superbus,* and from above downward presents first a convexity, secondly a broad groove, and thirdly another convexity; orbit nearly circular, more vertically placed and directed more outwardly than in *P. superbus;* postglenoid processes much less broad and proportionally deeper than in *P. superbus;* an angle of 45° is formed between the median line and a line passing through the postglenoid and paroccipital processes; length of skull about 12 inches; palate moderately produced; bullæ large, oval, and extend below level of postglenoid process; anterior part of squamosal juts out from malar below postorbital bridge.

Cope,[10] in describing *P. leidyi,* said that "a line drawn through the postglenoid and paroccipital processes makes (an angle of) 90° with the middle line" in this species. The angle in our specimens, as well as in the type according to Bettany, is 45°.

[10] Op. cit., p. 521.

In many respects this species is similar to *P. superbus*, except for smaller proportions. The incisive foramina are very nearly semi-circular, approach very close to the incisive alveoli, are large, and separated from each other by a very narrow strip of bone on each side of the sagittal plane. The basicranial axis is moderately steep, but much less so than in *P. macrostegus*. The occiput above the foramen magnum is strongly convex and the transverse crests are very close together. The overhang of the occiput is considerable. The molars have an internal cingulum. The skull is low and the cranium fairly wide. The zygomata rise to the top of the brain cavity, which is surmounted by a high narrow sagittal crest. The frontals are flat between the orbits. The side of the face is prominently divided by the upward convexity from the anterior zygomatic pedicle. The zygomata form a wide shallow U with the posterior crest turning backward internally and overhanging a position posterior to the postglenoid process. The lateral fossa above the condyle is quite shallow. The orbits are small and round and situated very high. The incisors are small.

Measurements.

	Holotype mm.	Cat. No. 10960 Y. P. M. mm.
Length of skull	330	331
Half width across frontal surface	54	54
Max. diameter from sagittal plane to external zygoma	83*	94
Max. diameter of brain case	73	73
Width between external surfaces of postglenoids	114	114
Depth of malar below orbit	40	38
Vertical diameter of orbit	46	38
Transverse diameter of orbit		35
Length of superior dental series, inc. canine		156
Length of superior premolar series		47.5
Length of superior molar series		76
Length of last molar	38	35
Max. length of ramus	254	

* Approximate.

Specimen No. 10965, of the Marsh Collection, possesses complete mandibular rami with teeth except incisors.

The total length is 250 mm. The masseteric fossa is quite deep and oval-shaped. The condyle and coronoid are of about equal height. The length of the inferior molar series is 77 mm. and that of the premolars, including the canine, 68 mm. The depth from the condyle to the angle is 138 mm. Specimen No. 10994, from Bridge Creek, has a very heavy outer margin on the squamous portion of the zygoma, and the bullæ do not extend below the postglenoid. No. 10966, from Clarno Bottom, and No. 10956, from Haystack Valley, are both slightly different from the type. The latter is apparently older stratigraphically than the majority of the specimens of this genus.

Fig. 1 A

Fig. 1 B.

Fig. 1.—*Promerycochœrus lulli*, sp. nov. Holotype. Cat. No. 10234, Y. P. M. A, right lateral view of skull and jaw; B, right half, superior view. × ¼.

Promerycochœrus lulli, sp. nov.

(FIGS. 1 A, B.)

Holotype, Cat. No. 10234, Y. P. M. Turtle Cove, John Day River, Oregon. Upper Oligocene (middle John Day).

Specific characters.—Lacrymal fossæ very deep and large; skull long and slender; face narrow; orbits look chiefly outward, but slightly forward and not upward; infra-orbital foramina small and located above P^4; sagittal crest very high and thin above posterior part of cranium, posteriorly curving over along the transverse crests, which are thin and close together; malar below orbit very thin but wide, posterior part of zygoma vertical, with crest rising nearly to the level of the squamous suture, and outer border rounded; masseteric fossæ shallow; face deep; muzzle square; inferior incisors crowded; bullæ large, extending to level of postglenoid processes; paramastoid and postglenoid processes very nearly close auricular fossa below; zygomatic arches originate above anterior portion of M^2, with convexity extending forward for short distance; cranium parallel-sided up to squamous suture, in front of which is marked groove; occiput above foramen magnum very narrow and convex, with exceedingly deep lateral fossæ.

The skull, jaws, and cervicals are still united by matrix.

The species is named in honor of Professor Richard Swann Lull.

Measurements of Holotype.

	mm.
Total length of skull	378
Bipostglenoid diameter	97
Bizygomatic diameter	195
Max. diameter of postglenoid process	27
Length of hyoid bones	71
Length of superior molar series	85
Length of superior premolar series	76
Length of superior dental series, inc. canine	186
Depth of malar below middle of orbit	51
Max. width of cranium	65
Diameter of postorbital constriction	51
Max. height of zygoma above glenoid surface	58
Width of frontal above middle of orbit	100*
Height of skull above parapet of M^3	109
Width of face at infra-orbital foramina	65
Depth of paramastoids below postglenoid process	29.5
Length of inferior molar series	88
Length of inferior premolar series	84
Depth of ramus from condyle to angle	139
Length of ramus	290

* Approximate.

Promerycochœrus latidens, sp. nov.

(Figs. 2 A, B, C.)

Holotype, Cat. No. 10961, Y. P. M. Upper Oligocene (upper John Day), North Fork, John Day River, 15 miles from its junction with the main stream, Oregon.

Specific characters.—Great bizygomatic diameter; malar very wide below orbit; lacrymal fossæ well marked;

Fig. 2 A.

Fig. 2 B.

Fig. 2 C.

Fig. 2.—*Promerycochœrus latidens*, sp. nov. Holotype. Cat. No. 10961, Y. P. M. A, right lateral view of skull; B, left half, inferior view; C, right half, superior view. × ¼.

vertical diameter of orbits slightly greater than transverse; zygomatic arch shallow V-shaped; infra-orbital foramen above P^4; bullæ relatively small, and triangular in basal outline; palate moderately produced posteriorly; no internal cingulum on superior molars.

The specimen selected as the type consists of a skull of which the portion anterior to P^1 is broken away. The teeth are much worn and the sutures nearly obliterated, due to old age. The skull is, however, remarkably well preserved.

This species resembles *P. chelydra* in its great width. The total skull length is slightly greater than that of *P. macrostegus,* or approximately 385 mm., while the bizygomatic diameter is 278 mm., or more than 13 per cent greater than in that species. The malar below the orbit is flat and directed somewhat obliquely outward and downward. Its width in *P. macrostegus* is 38.5 mm.; in *P. chelydra,* 40 mm.; in *P. superbus,* 38 mm.; and in *P. latidens,* 58 mm. The malar of *P. chelydra* is gently concave, while the lacrymal fossæ are less deep and smaller than in the latter species. The orbits look chiefly outward and but little forward or upward, thus differing from the position of those in *P. chelydra,* where they are even more oblique than in *P. superbus.*

The anterior part of the squamosal is inserted into the malar below the posterior half of the orbit, whereas in *P. chelydra* it is not protuberant below the orbit. The apex of the squamosal portion of the zygoma is much below the level of the sagittal crest, but in *P. chelydra* it is nearly on a level with the crest. This posterior section rises much less vertically than in *P. macrostegus,* but the outer edge is rounder and heavier than in the last named species. The inferior edge of the malar below the orbit is thickened, quite rugose, and offset from the alveolar parapet a distance of 24 mm.; that of *P. chelydra* is thin and slightly convex downward. From below the postorbital bridge to the glenoid process, the malar forms a sharp ridge, more pronounced than in any other John Day form. It is continued as a ridge of the maxillary to opposite the middle of the second molar, and thence forward as a convexity, dividing the side of the face into two concave portions. The postorbital bridge is wider and heavier than in *P. macrostegus.*

The cranium is wide and the sagittal crest high and

prominent. The inferior surfaces of the bullæ are deeply pitted. These bullæ are proportionally small and compressed; in *P. macrostegus* they are the smallest in the genus and are cone-shaped, while in *P. latidens* they extend from the anterior third of the paroccipital process to a line passing through the middle of the glenoid articular surface, but in *P. chelydra* they are small and subconical. The bullæ extend as far as, but not below, the inferior edge of the postglenoid, in which they differ from those both in the last named species and in *P. macrostegus.* The surface of the glenoid articulation is 70 mm. in length, while in the latter species, one of the longest of the genus, it is somewhat less than 60 mm.

The occiput is much more overhanging and the transverse crests spread much farther apart than in *P. macrostegus.* The height of the occiput above the base of the occipital condyles is 110 mm. in the latter species and 120 mm. in *P. latidens.* There is a very strong convexity above the foramen magnum, as in *P. macrostegus,* whereas in *P. chelydra* the convexity is wide and shallow. This convexity is separated from the posterior temporal angles by very deep lateral fossæ. The coössified mastoid and paramastoid processes do not close the auricular fossa below in *P. macrostegus,* but in this species they come extremely close to the postglenoid, although not actually forming a contact. The paramastoids are triangular shaped and robust; not nearly so slender as in *P. macrostegus.* They abut directly against the bullæ.

Measurements of Holotype.

	mm.
Total length of skull, approx.	385
Bipostglenoid diameter	143.5
Bizygomatic diameter	274
Length of superior molar series	79
Length of superior premolar series	69.5
Max. width of cranium	113.5
Diameter of postorbital constriction	72.3
Max. height of zygoma above glenoid surface	65.7
Width of frontal above middle of orbit	121.5
Width of face at infra-orbital foramina	87
Distance from M^3 to posterior margin of occipital condyles in median plane	148
Ant.-post. diameter of M^3	36

The palatal vault is wide and up-arched, with the dental parapet projecting well below. The concavity in *P. macrostegus* and in *P. chelydra* is greater. The width of the palate at the hypocone of M^3 is 64 mm.; at P^4, 55 mm. The metastyle of M^3 is very robust and the tooth as a whole is more like that of *P. superbus* than of *P. macrostegus*. The triturating surface of M^1 is completely obliterated, although this has been brought about in a somewhat different manner than in *Merycochœrus*. The muzzle is compressed, being 81 mm. in depth at P^1. The posterior nares are very large and the basicranial axis is steep.

FIG. 3.

FIG. 3.—*Promerycochœrus inflatus*, sp. nov. Holotype. Cat. No. 10233, Y. P. M. Right lateral view of skull. × ¼.

Promerycochœrus inflatus, sp. nov.

(FIG. 3.)

Holotype, Cat. No. 10233, Y. P. M. Upper Oligocene (upper John Day), Bridge Creek, John Day River, Oregon.

Specific characters.—Skull very robust and massive; incisive foramina large, close together, and approach near to incisive alveolar border; bullæ robust and rotund, extending slightly below postglenoid process; internal cingula on molar teeth; squamous portion of zygomatic arch very light proportionally, its posterior ascending section rising not above the middle of the orbit, but the malar section is wide and very robust, originating above the anterior part of M^2, and continuing forward as a convexity which occupies nearly the whole side of the face; lacrymal fossæ very shallow; cranium very wide and low; frontals very wide and flat; orbits look somewhat upward and forward, but chiefly outward; sagittal crest long and thin; palate wide;

postglenoid processes relatively small; palate moderately produced; wide interval between paroccipital and postglenoid processes; infra-orbital foramen above P^4-M^1 interval; exceedingly heavy metastyle on M^3.

The type consists of a skull only. It is peculiar in that the bone of all parts of the skull is slightly spread apart and the interstices filled with matrix.

Measurements of Holotype.

	mm.
Total length of skull, approx.	400
Bipostglenoid diameter	170
Bizygomatic diameter	254
Length of superior molar series	94.3
Length of superior premolar series	78.5
Length of superior dental series, inc. canine	200
Depth of malar below middle of orbit	49.7
Width of palate at P^4	78
Width of palate at protocone of M^3	69
Max. width of cranium	138
Diameter of postorbital constriction	82
Max. height of zygoma above glenoid surface	58
Width of frontal above middle of orbits	140*
Width of face at infra-orbital foramina	130

* Approximate.

Promerycochœrus marshi, sp. nov.

(Figs. 4 A, B.)

Holotype, Cat. No. 10999, Y. P. M. Upper Oligocene (upper John Day), Haystack Valley, John Day River, Oregon.

Specific characters.—Malar below orbit very wide and heavy; orbits small; lacrymal fossæ deep; zygoma very heavy; nasals project to a point above the anterior portion of the canines; infra-orbital foramen above P^4; masseteric fossæ very deep; face narrowed in advance of the orbits more than in any other species; frontals flat and decurved above orbits; temporal ridges have their junction above a line through postglenoid processes, which is more posterior than in any other species of the genus; incisive foramina large and separated by a triangular wedge of the palate, the apex of which is close to the incisor border. In all the other species, the proximal sides of the foramina are parallel to the sagittal plane, instead of being markedly oblique as here.

The holotype consists of the skull and jaws of a fully adult animal, as well as the atlas, axis, five cervicals, two

dorsals, and the proximal parts of the first three ribs articulated and partly enclosed by matrix. The skull and jaws, which have not been separated, show a similarity to *P. macrostegus,* but the differences are too great and too important to identify it with that species. The skull is

Fig. 4 A.

Fig. 4 B.

Fig. 4.—*Promerycochœrus marshi,* sp. nov. Holotype. Cat. No. 10999, Y. P. M. A, right lateral view of skull and jaw; B, right half, superior view. × ¼.

slightly longer and much more robust than in the latter. In this specimen the orbits are not so high, are smaller, and more nearly round; malar is much wider and heavier; infra-orbital foramen smaller; nasals project farther forward; face much deeper above the premolars; mandibles heavier and masseteric fossa very much deeper; incisive foramina much closer together, larger, of differ-

ent shape, and approach much more closely to the incisor border; sagittal crest very much shorter; greater convexity above foramen magnum, and lateral fossæ deeper; zygomatic crest not so high and the outer margin of the process less robust; face not so clearly divided by the convex prolongation of the zygoma. Width of the malar below the orbit, 53 mm.; in *P. macrostegus,* 38 mm.; in *P. chelydra,* 40 mm.; and in *P. latidens,* 58 mm.

The specific name is given in honor of Professor O. C. Marsh.

Measurements of Holotype.

	mm.
Length of skull, approx.	380-385
Bipostglenoid diameter	136
Bizygomatic diameter	244
Length of superior molar series	85
Length of superior premolar series	76
Length of superior dental series, inc. canine	186
Max. width of cranium	116
Max. width of postorbital constriction	68
Max. height of zygoma above glenoid surface	69
Width of frontals above middle of orbits	111
Height of skull above parapet of M^3	115
Width of face at infra-orbital foramina	86
Length of nasals	166
Depth of paramastoids below inferior edge of postglenoids.	36
Distance from nasion to junction of temporal ridges	138
Length of inferior molar series	92
Length of inferior premolar series	81.5
Length of inferior dental series, inc. canine	173.5
Depth of ramus from condyle to angle	146
Length of ramus	294
Max. width of atlas	126
Length of centrum of axis, exc. of odontoid process	52
Length of centrum of third cervical	32
Height of third cervical, exc. of spine	52
Length of centrum of fourth cervical	34
Length of centrum of fifth cervical	35
Length of centrum of sixth cervical	33
Length of centrum of seventh cervical	33
Length of centrum of first dorsal	33
Length of centrum of second dorsal	33
Length of centrum of third dorsal	35
Width of spine at top of neural arch, fifth cervical	12.7
Width of spine at top of neural arch, sixth cervical	18
Width of spine at top of neural arch, seventh cervical.	18
Width of spine at top of neural arch, first dorsal	29.5
Width of spine at top of neural arch, second dorsal	26.5
Width of spine at top of neural arch, third dorsal	24.8

Promerycochœrus microcephalus, sp. nov.

(Figs. 5 A, B.)

Holotype, Cat. No. 10998, Y. P. M. Upper Oligocene (middle John Day), Turtle Cove, John Day River, Oregon.

Specific characters.—Skull long and narrow; frontals markedly decurved above orbits; extremely small brain

Fig. 5 A.

Fig. 5 B.

Fig. 5—*Promerycochœrus microcephalus*, sp. nov. Holotype. Cat. No. 10998, Y. P. M. A, left lateral view of skull and jaw; B, left half, superior view. × about 1/3.

chamber; high narrow sagittal crest; frontal ridges continued separate and nearly parallel to a position above the condyles before their junction; squamous portion of

zygoma extends but slightly above squamous suture; malar below orbit very wide and heavy, with its inferior edge strongly convex downward; nasals extend nearly to incisive alveoli; lacrymal fossa well marked, moderately deep; orbit triangular, with apex downward and forward; very deep lateral fossæ above condyles; no internal cingulum on molars; bullæ large and extending below postglenoid processes; infra-orbital foramen above P^4.

This peculiar specimen consists of a skull, somewhat laterally compressed, but well preserved except for the portion anterior to P^1, which is broken away. The left mandible is complete except for the canine and incisors, which are missing. The right ramus has P_2, P_3, P_4, M_1, and parts of M_2 and M_3. The upper contour of the skull is nearly straight, the anterior portion of the nasals being nearly as high as the sagittal crest. The squamous portion of the zygoma is neither heavy nor rugose as in *P. macrostegus*, and its upper part curves strongly backward. The side of the face is divided by the convexity from the anterior zygomatic pedicle, with concavities above and below. The canine convexity is prominent.

Measurements of Holotype.

	mm.
Total length of skull	340*
Bipostglenoid diameter	104
Bizygomatic diameter	154
Length of superior molar series	81.7
Length of superior premolar series	68
Depth of malar below middle of orbit	49
Max. width of cranium	55
Diameter of postorbital constriction	38
Max. height of zygoma above glenoid surface	55*
Width of frontals above middle of orbits	95
Height of skull above parapet of M^3	106
Width of face at infra-orbital foramina	67
Length of nasal bones	145
Length of inferior molar series	82
Length of inferior premolar series	73
Depth of ramus from condyle to angle	137.5
Length of ramus	255*

* Approximate.

Desmatochœrus[11] *curvidens*, subgen. et sp. nov.

(FIGS. 6 A, B.)

Holotype, Cat. No. 10997, Y. P. M. Upper Oligocene (middle John Day), North Fork, John Day River, 15 miles above junction with the main stream, Oregon.

Specific characters.—Small size; infra-orbital foramen above posterior part of P^3; bullæ compressed, not extending below postglenoid process; steep basicranial axis; P_2 and P_3 crowded, unreduced; inferior border of ramus turns sharply downward below anterior part of M_3;

FIG. 6 A.

FIG. 6 B.

FIG. 6.—*Desmatochœrus curvidens*, subgen. et sp. nov. Holotype. Cat. No. 10997, Y. P. M. A, left lateral view of skull and jaw; B, left half, inferior view. × about 3/8.

[11] *δέσμα*, bond, + *χοῖρος*, hog, in allusion to its being the link between *Eporeodon* and *Promerycochœrus*.

zygomatic arch narrow immediately in advance of the glenoid process, continuing forward and upward in a strong convexity on the side of face, more as in *Eporeodon* than in *Promerycochœrus;* lacrymal fossæ deep but small; depth of malar below orbit, 29 mm.; hypocone of M_3 noticeably smaller than protocone; internal cingulum on superior molars but faintly developed; transverse crests near together; very strong convexity above foramen magnum; crest of zygoma low and directly above glenoid process. Shape of the canine more like that of a carnivore than an herbivore.

The holotype, consisting of the skull and jaws, appears to be one of the earliest Promerycochœri, and apparently connects the Eporeodons with this genus. The total length of the skull is but about 30 mm. longer than the largest *Eporeodon.* It differs, however, from *Eporeodon* in the following features: (1) the postglenoid processes are robust and prominent; (2) the bullæ are large and laterally compressed, but less prominent than the postglenoid processes, whereas in *Eporeodon* the bullæ are very large and the postglenoids always relatively very small; (3) the condyles are heavier, of different shape, and more widely separated at the basion; (4) in *Eporeodon* the highest point of the zygoma is near the middle of the temporal fossa, but in this species, the squamous part trends upward, as in the other Promerycochœri, above or just in advance of the glenoid articular surface; (5) the infra-orbital foramen is above the posterior part of P^3, while in *Eporeodon* it is normally above the anterior part of P^3, and in the other species of *Promerycochœrus,* either above P^4 or above the interval between P^4 and M^1; (6) the basicranial axis is steep, a condition frequently found in *Promerycochœrus,* but not in *Eporeodon.*

This species resembles *Eporeodon* in that (1) the metastyle of M^3 is not rotated as far inward as is usual in *Promerycochœrus,* but has more the position found in the other genus; (2) the hypocone of M^3 is smaller than the protocone, whereas in the other species they are normally nearly equal in size; (3) its size is close to that of the larger Eporeodons; (4) the inferior border of the ramus does not so closely parallel the alveolar border as in the latter genus (in *Promerycochœrus* the inferior border projects downward toward the angle gradually, beginning beneath the posterior portion of M^3); (5) the

anterior part of the zygoma is neither wide nor robust, but has much the shape found in *Eporeodon;* (6) from the matrix and other factors it is very probably a middle John Day form, this horizon having produced the greatest number and variety of species of *Eporeodon.*

Measurements of Holotype.	mm.
Length of skull, condyles to prosthion inc.	279
Bipostglenoid diameter	95
Bizygomatic diameter	153
Length of superior molar series	68
Length of superior premolar series	55
Length of superior dental series, inc. canine	146
Max. width of cranium	70
Max. height of zygoma above glenoid surface	46
Width of frontals above middle of orbits	76
Length of inferior molar series	73
Length of inferior premolar series	62
Depth of ramus below M_1	38

Synopsis of Characters of John Day Species of Promerycochœrus.

1. Infra-orbital foramen above middle of P^4; palate moderately produced posteriorly.
   - Orbits small, nearly round; internal cingulum on superior molars; skull elongated; bullæ large; lacrymal fossa very shallow; incisive foramina right-triangular, with longest leg along sagittal plane .... *P. superbus.*
   - No internal cingulum on superior molars; greatest bizygomatic diameter anterior to glenoid process; bullæ small, subconical; incisive foramina wider than long and close to base of canines .*P. chelydra.*
   - Orbits nearly circular; internal cingulum on superior molars; lacrymal fossa conical, deep; incisive foramina nearly semicircular and close to incisor margin; bullæ large; smaller than *P. superbus* .... *P. leidyi.*
   - Orbits looking outward, not upward; lacrymal fossa very deep, large; skull long, slender; sagittal crest exceedingly high and thin; bullæ large, compressed; occiput above foramen magnum very narrow and convex .... *P. lulli.*
   - Orbits looking chiefly outward; lacrymal fossæ well

marked; greatest bizygomatic diameter of any John Day species of the genus; great depth of malar below orbit; zygoma V-shaped; no internal cingulum on superior molars ....*P. latidens.*

Orbits small, nearly circular, very short sagittal crest; malar wide; lacrymal fossa deep; face narrow; incisive foramina large, set obliquely from sagittal plane; skull large, massive ....*P. marshi.*

Skull long, narrow; extremely small brain chamber; very high narrow sagittal crest; frontals separate, parallel to a point above condyles before junction; malar wide; no internal cingulum on superior molars; bullæ large; lacrymal fossæ moderately deep ....*P. microcephalus.*

2. Infra-orbital foramen above interval between M^1 and P^4.

Orbits very high; palate much produced posteriorly; no internal cingulum on superior molars; bullæ small, conical; lacrymal fossa small; skull longer than in *P. superbus;* incisive foramina large, oval-shaped ....*P. macrostegus.*

Orbits small, looking chiefly outward; palate moderately produced; internal cingulum on superior molars; lacrymal fossæ very shallow; malar very wide; squamous part of zygoma weak, not rising above middle of orbit; bullæ rotund ...*P. inflatus.*

3. Infra-orbital foramen above posterior half of P^3.

Small size; basicranial axis steep; lacrymal fossæ deep, small; internal cingulum on superior molars but faintly developed; crest of zygomatic arch low; true *Promerycochœrus*, but close to *Eporeodon* ....*Desmatochœrus curvidens.*

ART. XV.—*Episodes in Rocky Mountain Orogeny;* by C. L. DAKE, Missouri School of Mines.

In a recent article in the Journal of Geology, Dr. Chamberlin calls attention to the dual nature of the Rocky Mountain or Laramide revolution,[1] in which "at least two distinct periods of folding have been distinguished." He also notes that similar conditions obtain in southwestern Wyoming. The present writer is in possession of confirmatory evidence, from northwestern Wyoming, showing distinctly more than one episode of disastrophism in the locality between Cody and Yellowstone Park. The facts upon which this statement is based have in part been presented by the writer in a previous paper.[2] The facts already made public, together with those not heretofore published, may be briefly summed up as follows.

In Sec. 21, T. 52 N., R. 104 W., south of Morris Post Office, occur nearly flat-lying outcrops of pebbly sandstone interbedded with red and gray shales, provisionally assigned to the Fort Union(?) as that term is used by Hewett, in the Shoshone River Section.[3] The pebbles in these beds are abundant and average one-fourth to one-half inch in diameter but reach a maximum of over two inches. They are well rounded and include red granite, basalt, brown quartzite, sandstone, black chert, brown chert, and shale. The red granite is wholly similar to that found in the pre-Cambrian of the region, and the cherts can be duplicated in the Carboniferous rocks. No granites are known in this locality younger than pre-Cambrian, and no source for the cherts more recent than the Embar (Pennsylvanian). The quartzite is comparable to the Quadrant (Tensleep) quartzite (Pennsylvanian) exposed fifteen or twenty miles north of here. Hewett,[4] in the Shoshone River Section, found cherts with Pennsylvanian faunas in apparently equivalent beds of Fort Union age; also pebbles of pink granite in the same beds. The pebbly sandstone rests on beds of Cody (Colorado-Montana) age, and the presence of pebbles of pre-Cam-

[1] Chamberlin, Rollin T.; The Building of the Colorado Rockies, Jour. Geol., XXVII (1919), pp. 151-164 and 225-251.

[2] "The Hart Mountain Overthrust and Associated Structures in Park County, Wyoming," Jour. Geol., 26, pp. 45-55, 1918.

[3] Hewett, D. F.; The Shoshone River Section, U. S. Geol. Survey, Bulletin 541, pp. 89-113.

[4] Hewett, op. cit., p. 105.

brian granite included in the conglomerate involves the erosion of part of the Cody (probably 1000 feet or more), the Frontier (500 ft.), the Mowry and Thermopolis (900 ft.), the Cloverly (100 ft.), the Morrison (500 ft.), the Sundance (500 ft.), the Chugwater (700 ft.), the Embar (100 ft.), the Tensleep (100 ft.), the Amsden (200 ft.), the Madison (1000 ft.), the Bighorn (300 ft.), and the Deadwood (800 ft.), all of which are known in the section within ten miles of this point. This indicates a minimum total of at least 6,000 feet of sediments; probably much more if the equivalent of the Mesa Verde, Meteetsee, and Ilo (Lance) were at one time present, as they presumably were, in the time before the pebbly sandstone was laid down. At least they are known to underlie the Fort Union in the Shoshone River section, just east of Cody. Including these formations and assigning to them the thicknesses known to occur within a few miles of this locality (the Shoshone River Section) would bring the grand total up to at least 11,000 feet.

The removal of so great a thickness of beds by erosion, in the interval before the laying down of the pebbly beds, necessitates pronounced uplift of the region, and quite probably involves the formation and truncation of sharp folds. If more evidence is needed for this first phase of the diastrophism, it is to be found in Sec. 34, T. 50 N., R. 102 W., on the divide between Sage and Meteetsee Creeks, where similar pebbly sandstones rest with slight but distinct discordance on Cody shales, the divergence in dips being perhaps as great as ten degrees. The pebbly sandstones in this latter locality are not continuous in outcrop with those of the former area, but there can be little doubt that they belong to the same formation. Still further confirmation is probably to be found in Sections 11 and 12, T. 50 N., R. 105 W., where similar pebbly sandstones rest, at nearly uniform elevation, in successive contact against Cody, Frontier, and Thermopolis beds. The area was not studied in detail, and the relations could conceivably be those of faulting, but it is more than probable that the situation represents unconformity, in which the older beds occur in a truncated fold, buried by the pebbly sandstone. Thus it seems probable that the first episode of the diastrophism was marked not alone by broad uplift and erosion but also by considerable folding, with accompanying truncation of the folds.

It might be noted here that Fisher[5] mentions and illustrates marked angular unconformity between the Wasatch and Laramie, near Hart Mountain, north of Cody, but that he does not recognize Fort Union in his sequence, where Hewett later differentiated it,—so that it is not possible to say whether or not the Fort Union is involved in this angular unconformity, as he describes it.

Hewett and Lupton[6] describe the Fort Union as overlapping with angular unconformity from Lance (Ilo) onto Meteetsee, in other portions of the Big Horn Basin, clearly indicating pre-Fort Union folding and erosion.

The second episode of deformation followed the deposition of the pebbly (Fort Union ?) sandstone. Near the Middle Palatte Ranch, on Greybull River, in the W. ½ Township 48 N., Range 103 W., is a marked anticline, in which the pebbly sandstone above mentioned partakes of the folding, with dips up to 15 or 20 degrees, on the east flank of the fold. Similarly, Hewett[7] reports the Fort Union to be dipping about 37° in the Shoshone River Section, and Hewett and Lupton[8] refer to the Fort Union beds as being involved in the folding.

One of the most interesting features of this, or probably of a still later episode of deformation is the association, with the folding, of enormous overthrust faults. In the locality first described, Sec. 21, T. 52 N., R. 104 W., and at numerous nearby points, the large fault known as the Hart Mountain Overthrust, has shoved Madison (Mississippian) limestone out over the pebbly beds here referred to as Fort Union(?). As the writer has already pointed out,[9] the Madison is not actually seen to rest on the sandstone, but at many points the sandstone occurs near the foot of bold Madison scarps. If the beds had been laid down against these cliffs, after faulting, they should contain an abundance of pebbles and bowlders of the limestone, such as now strew these slopes. Very careful search fails to reveal any such pebbles, even where the beds lie in closest proximity to the Madison scarps; and this fact alone constitutes practically positive proof that

[5] Fisher, C. A.; Geology and Water Resources of the Big Horn Basin, U. S. Geol. Survey, Prof. Paper No. 53, pl. X, and p. 37.

[6] Hewett, D. F., and Lupton, C. T.; Anticlines in the Southern Part of the Big Horn Basin, Wyoming, U. S. Geol. Survey, Bulletin 656, pp. 28-29.

[7] Hewett, D. F.; op. cit., p. 110.

[8] Hewett, D. F., and Lupton, T. C.; loc. cit.

[9] Jour. of Geol., 26, pp. 53-54, 1918.

the sandstones pass under the Madison rather than lap against the fault scarp.

It is definitely established, then, that there were, in this region, at least two well-marked episodes of deformation, one being pre-Fort Union(?), as the term is here used, and the other post-Fort Union (?). Plate VI B of the report of Hewett and Lupton[10] shows Fort Union beds, themselves dipping at notable angles, resting with plainly visible discordance on more steeply dipping Lance (Ilo) beds, and constitutes a decidedly graphic representation of the facts.

The dating of the above episodes depends upon the correct correlation of the beds involved. The latest beds disturbed by the first deformation, in the area studied, are Cody shales, the upper members of which are probably Pierre. Farther east, Mesa Verde, Meteetsee, and Ilo (Lance) are probably also involved. This makes the first disturbance post-Cody, probably post-Lance. And it was closed, or at least in quiescence, before the pebbly beds were laid down. The utmost importance, then, attaches to the age of these pebbly beds.

The writer has already given his evidence[11] for believing that they are the Fort Union of Hewett's Shoshone River Section. This, together with some additional evidence, is here summed up briefly. The formation described consists of buff to bright yellow sandstone, in beds two to twenty feet thick, alternating with shaly members which are dominantly gray, but which contain occasional red layers. The sandstones are prominently and intricately crossbedded, and carry many large sandstone concretions of a darker color (brown to gray) very resistant to weathering, which protrude from the surface of outcrops and at many places lie strewn abundantly over the surface of the ground. At many points, and in several beds, the sandstones are distinctly conglomeratic, the pebbles consisting of red granite and pegmatite, basalt, brown quartzite, sandstone, black and brown chert, and shale. They are well-rounded, and average from one-fourth to one-half inch, but in rare cases exceed two inches. Thin seams of lignite were noted at various horizons, and one workable seam of coal was noted, from

[10] Hewett, D. F., and Lupton, T. C.; loc. cit.
[11] Dake, C. L.; loc. cit.

which there was a small local production. No identifiable fossils, plant or animal, were found.

These beds were mapped by Hague[12] as Pierre and Fox Hills, and are probably the same beds mentioned in one paper by Hewett[13] as "Tertiary sandstones and shales probably of Wasatch age." At this point they were probably not carefully examined by Hewett. Several facts seem to favor the correlation of these beds with the Fort Union of Hewett's Shoshone River Section, rather than with Wasatch.

The pebbles of these beds are significant. Hewett,[14] in describing the Gebo, Meteetsee, and Ilo formations, mentions no conglomeratic material whatever. In the descriptions of the equivalent Mesa Verde (Gebo), Meteetsee, and Lance (Ilo), Hewett and Lupton[15] similarly make no mention whatever of pebbles, though both papers describe the Fort Union as characteristically pebbly, and both mention the occurrence of red granite, quartzite, and Carboniferous cherts among the pebbles. This situation would lead to the conclusion that the pebbly beds of the present paper are far more likely to be the equivalent of Fort Union than of older beds.

Similarly neither of the reports cited describes red clay in beds of Mesa Verde (Gebo), Meteetsee, or Lance (Ilo) age, though both mention its presence in the Fort Union, a fact that would relate the red-clay-bearing pebbly sandstones to the Fort Union, rather than to older beds.

The angular unconformity at the base of the pebbly sandstones finds its counterpart in the angular unconformity described by Hewett and Lupton[16] at the base of the Fort Union, and tends to confirm the above conclusions. The statement, also made by Hewett and Lupton, that the Fort Union carries coal in the west side of the Big Horn Basin, is further favorable to such a correlation, especially in view of the fact that they report the Wasatch non-coal-bearing in the Big Horn Basin.

The considerably folded condition of these beds also fits with the folding known in the Fort Union, while it is

[12] Hague, Arnold; Absaroka Folio, U. S. Geol. Survey, Folio 52.
[13] Hewett, D. F.; Sulphur Deposits in Park County, Wyoming, U. S. Geol. Survey, Bulletin 450, p. 478.
[14] Hewett, D. F.; The Shoshone River Section, U. S. Geol. Survey, Bulletin 541.
[15] Hewett, D. F., and Lupton, T. C.; op. cit. pp. 26-28.
[16] Hewett, D. F., and Lupton, T. C.; op. cit., p. 28.

not characteristic of Wasatch. Nevertheless it must be remembered that both red clay beds, and conglomeratic beds, of similar character, are known in the Wasatch formation.

The large concretions noted so abundantly in these pebbly sandstones are apparently not described by either Hewett or Hewett and Lupton, in the above papers. Fisher[17] mentions similar concretions in the Laramie (which formation, as he used the term, includes present Mesa Verde, Meteetsee, and Lance), but does not indicate their horizon. The writer noted concretions of the same sort at two horizons in Fisher's Laramie, one near the base, probably in what is now mapped as Gebo or Mesa Verde, the other near the top, in pebbly beds quite certainly corresponding with the Fort Union. These observations were made on Frost Ridge and west into the valley of Sage Creek. Similar concretions are described from the Dakota sandstone near Minneapolis, Kansas.[18]

Lloyd and Hares[19] also report abundant concretions from the Fox Hills, also from the Lance formation, in South Dakota. According to Wegemann,[20] one of the most characteristic features of the Lance formation in the Powder River Basin is the presence of "large round concretionary masses that weather from the sandstone beds. These masses resemble great bowlders, and some of them are as much as 10 or 15 feet in diameter." In plate XXII A, of the above quoted paper, are shown several such concretions, and it must be admitted that from the photographs they closely resemble those found by the writer. While they point to possible correlation with the Lance, their evidence is probably offset by the other evidence cited, and by the occurrence of similar concretions at several different horizons.

In view of the above facts, the writer is reasonably convinced of the equivalence of the pebbly sandstones of this paper with the generally recognized Fort Union of the Big Horn Basin, as described by Hewett and Lupton, though this does not by any means make certain their

[17] Fisher, C. A.; op. cit., p. 31.

[18] Chamberlin, T. C., and Salisbury, R. D.; Geology, vol. II, p. 147.

[19] Lloyd, E. R., and Hares, C. J.; The Cannonball Marine Member of the Lance Formation, Jour. Geol., 23, pp. 523-547, 1915.

[20] Wegemann, C. H.; Wasatch Fossils in So-Called Fort Union Beds of the Powder River Basin, Wyoming, U. S. Geol. Survey, Prof. Paper 108 D, 1918.

identity with the type Fort Union. It is also by no means finally proved that the beds are not Wasatch, though the writer believes that their interpretation as Fort Union(?) is the more reasonable.

In addition to the data above presented, attention should also be called to the following facts. Hewett,[21] in his discussion of the Fort Union, notes that the lowest conglomerates of the group carry no igneous material. It is only near the middle of the formation that granite pebbles begin to be noted, and in the upper part is abundant red clay. The presence of red clay beds and granite pebbles in the pebbly beds studied by the writer would tend to suggest that they represent the upper, rather than the lower part of the Fort Union. The fact that the granite pebbles occur only in the middle and upper part of the sandstone probably indicates that the granite had not yet been uncovered by erosion, in early Fort Union time, and may quite probably be taken to mean that uplift was still progressing, and hence accelerating erosion, while the lower Fort Union was still in process of being deposited.

It seems clearly established, then, by the above facts, that there were in northwestern Wyoming two distinct episodes of Rocky Mountain deformation, both of which were post-Lance, as the Lance formation is differentiated in the latest reports on that region. The first is post-Lance, and pre-Fort Union(?), the second post-Fort Union(?), and clearly pre-Wasatch, since Hewett and Lupton[22] indicate widespread unconformity at the base of the Wasatch, "commonly recognizable by discordance in dip."

A late epoch of deformation includes the thrusting of great blocks of Mississippian limestone many miles out over the Fort Union(?) pebbly sandstones. According to recent work by Hewett[23] this thrusting is post-Bridger, since on McCulloch Peaks he finds Madison (Mississippian) limestone resting on beds of undoubted Bridger age. The major thrust plane has been notably warped; but this warping may have occurred as the faulting was going on. After the faulting, the fault blocks were deeply trenched by erosion, before the epoch of vulcanicity that buried the

[21] Hewett, D. F.; op. cit., pp. 104-106.
[22] Hewett, D. F., and Lupton, C. T.; op. cit., pp. 29-30.
[23] Hewett, D. F.; in a recent paper before the Geol. Soc. of Washington.

whole deeply under the Early Basic Breccia, believed by Hague[24] to be Neocene in age. The writer has found several clear cases of the lava and breccia overlapping the deeply eroded fault plane, from Mississippian above onto Cretaceous below. The fault, then, is post-Bridger and pre-Early Basic Breccia.

It is interesting in this connection to note that the Bannock overthrust[25] is known to pass beneath the Almy conglomerate said to be of Wasatch(?) age. Veatch, quoting Knowlton, however, says of the Almy,[26] "If correctly determined, the age should be Fort Union or near it." This would make the Bannock fault pre-Fort Union, whereas the Hart Mountain thrust is post-Bridger.

This, then, would appear to add to the post-Lance and pre-Fort Union folding, and to the post-Fort Union and pre-Wasatch deformation, a third episode, the post-Bridger and pre-Early Basic Breccia overthrusting.

Since in the region of the Big Horn Basin, these episodes are repeatedly shown in a single section, or at least in a very limited locality, this distinct nature does not depend for proof upon distant correlation. When one tries, however, to correlate these episodes with those of other localtities, the problem becomes vastly more complicated.

The first episode noted by Chamberlin[27] in Colorado is post-Montana and pre-Arapahoe. He does not state definitely that this disturbance involved more than uplift and erosion, but by inference he carries the impression that it is to be correlated with profound folding and faulting in Wyoming. If, as he states, the pre-Arapahoe interval involves the removal of 14,000 feet of sediments, it seems certain that folding, of at least moderate intensity, must be assumed, since broad uplift of the general region to such an extent is hardly to be considered.

Now it is a well-known fact that the Arapahoe beds of the Denver Basin are rather generally correlated with the Lance of the type area.* Further, the three episodes of diastrophism noted in Wyoming are post-Lance, as that term is used by Lupton and by Hewett in the Big Horn

[24] Hague, Arnold, Absaroka Folio, U. S. Geol. Survey, Folio 52.

[25] Richards, R. W., and Mansfield, G. R.; The Bannock Overthrust, Jour. Geol., 20, pp. 681-709, 1912.

[26] Geology and Geography of part of Southwestern Wyoming, U. S. Geol. Survey, Prof. Paper 56, p. 90.

[27] Chamberlain, R. T.; op. cit., p. 153.

Basin. This then forces us to one of three conclusions. Either (1) the first phase of the Rocky Mountain folding in Colorado is actually earlier than any of those described in Wyoming, being actually pre-Lance while they are post-Lance; or (2) the Arapahoe is not the true equivalent of the Lance of the type locality; or else (3) the so-called Lance of the Big Horn Basin is not the exact equivalent of the original Lance. The writer has been unable to find the necessary data for a solution of this threefold possibility. We should probably hesitate before postulating another period of folding in Rocky Mountain orogeny, especially in view of the uncertain state of the Fort Union-Lance-Laramie correlation. There are those who believe that diastrophic evidence will be the final criterion in settling this problem. It is admitted that diastrophism is a valuable aid in correlation, but before it can be used in settling this problem, we must know quite beyond doubt whether or not there are more than three episodes in the orogeny of the Rocky Mountains, and unless evidences of a fourth can be found in the same restricted area where the three have already been proved, it seems to the writer that to make a final determination must rest on other methods of correlating the strata involved, across wide intervening areas.

In this connection it is pertinent to inquire into the relations of the Lance to the underlying beds in the type area and in the Big Horn Basin, to discover whether there is at its base any break comparable to that reported below the base of the Arapahoe beds of Colorado.

Wegemann,[28] in the Powder River Basin of eastern Wyoming, described the Lance formation as carrying a few thin coal seams and many notable concretions, and as being without evidences of unconformity at either base or top, but describes unconformity between the Fort Union and Wasatch.

According to Knowlton,[26] in Carbon County, Wyoming, the "upper Laramie" (Lance) rests on the lower Laramie with "distinct change in the dip, apparently a slight change in the strike, and a marked change in the lithology between the lower and upper beds." "Not only are the beds * * * above more than 6000 feet of 'Laramie' rocks

[28] Wegemann, C. H.; loc. cit.

[26] Knowlton, F. H.; Further Data on the Stratigraphic Position of the Lance Formation (Ceratops Beds), Jour. Geol., 19, pp. 358-376, 1911.

* * * but also they are separated from the 'Laramie' ('Lower Laramie') by an unconformity, which, according to Veatch, is profound and has involved the removal of perhaps as much as 20,000 feet of sediments.'' He also says that the Lance is ''stratigraphically, structurally, and paleontologically inseparable from the Fort Union.'' This latter statement will certainly not hold for the Lance and Fort Union, as those terms are used in the Big Horn Basin by Lupton and Hewett.

Concerning an area between Cheyenne River and Cannonball River, Knowlton further says, ''Above the Fox Hills, but as will be shown later, with the intervention in places of a distinct unconformity, comes the Lance formation, above which, but without unconformity or other observed break, is the acknowledged Fort Union.'' Stating the proposition more generally, he says of the relations of the Lance to the Fort Union, ''There is yet to be observed a single locality at which unconformable relations have even been suspected.'' This also is contrary to the Big Horn Basin conditions. There, Hewett and Lupton[30] call attention to angular unconformity between Lance and Fort Union, but mention no unconformity at all at the base of the Lance. Similarly, Hewett[31] fails to mention any unconformity at the base of his Ilo (Lance) formation.

The data presented above favor the conclusion that the Lance and Arapahoe beds are correctly correlated and that there is a true pre-Lance epoch of deformation in both the Eastern Wyoming-Western Dakota area and in Colorado. What then is the answer to the apparent exception in the Big Horn Basin, where all the epochs of folding appear to be post-Lance? We can probably not answer that question, until the correlation between the Big Horn Basin and the type Lance is more thoroughly worked out.

Incidentally it may here be noted that the occurrence of a typically marine Fox Hills fauna in undoubted Lance beds[32] tends to tie the Lance more closely with marine Cretaceous than with the terrestrial Tertiary beds.

[30] Hewett, D. F., and Lupton, C. T.; loc. cit.
[31] Hewett, D. F.; loc. cit.
[32] Lloyd, E. R., and Hares, C. J.; loc. cit.

Art. XVI.—*Relations of Subjacent Igneous Invasion to Regional Metamorphism*; by Joseph Barrell.

(Continued from page 186.)

PART III. INTERPRETATION OF DYNAMO-METAMORPHIC FEATURES IN THE ROOFS OF BATHOLITHS IN MOUNTAIN PROVINCES.

Preliminary Statement.

This article has reached the point where it appears that batholithic invasion is to be looked upon as one of two major factors in the control of the phenomena of dynamo-metamorphism, the other being crustal deformation. The following part will consequently be a study of significant features and their interpretation as phenomena of magmatic injection, chemical alteration, and lateral compression of batholithic roofs.

Features Produced by Movements of Solutions and Selective Crystallization.

Where blocks of biotite granite gneiss are inclosed in a coarse granite, it may frequently be observed that a concentration of biotite from the surrounding magma has taken place within and around such fragments. Pegmatitic seams in banded gneisses usually show no change at the margins, but may sometimes be seen to have a biotite lining which slightly permeates the walls and gives sharper definition to the seams. This tendency for biotite to separate by selective crystallization from highly aqueous solutions of magma is to be related with that normal sequence of crystallization in magmas whereby the black bisilicates, associated with smaller amounts of other minerals, crystallize out early, followed by the crystallization of plagioclases, then orthoclase, then orthoclase and quartz; each phase overlapping the adjacent ones. Now if the magma is rising through the foliated structure of a roof and especially if the amount of water is large, so that the crystals of any one generation are but a small part of the magma, the result is a vertical separation of the magma by fractional crystallization. The biotite will be strained out in one place and crystallize against biotite. Quartz and feldspar will rise higher and crystallize as pegmatite free from biotite. Where the magma rises through a foliated country rock, it should lead to a pronounced banding in composition, giving banded gneisses.

It is in this way, by the movement of solutions along foliation planes, rather than by a mere recrystallization in place, that marked lamellar segregation of minerals in gneisses is most readily explained. Let a massive granite yield to lateral pressure by granulation or recrystallization: the minerals are broken down and reconstructed, but in this reconstruction laminæ of quartz and feldspar tend to alternate with those of mica. Mere molecular diffusion and crystallinic attraction would tend to build up individual minerals elongated in the plane at right angles to compression, but would tend to reconstruct the minerals about each dominating nucleus without extending one kind of mineral into continuous sheets. This kind of massive gneiss is fairly common in those types where granulation has exceeded recrystallization as the agent of deformation, in other words, where regional compression has been strong and crystallizing solutions scanty.

Where, however, the solvents are more abundant, movement would take place readily along the foliation direction, very slowly across it, the biotite would be progressively concentrated into layers, the quartz and feldspar would tend to be carried farther along the planes and have the relations of intercrystallized laminæ. If the solvents rise far and are concentrated into thicker sheets, it is a form of pegmatization carried on not as a result of a primary crystallization of magma, but as a result of rock-mashing in the presence of rising solutions. Pegmatization, as Van Hise has noted, may occur in association with formations which show no relationship to igneous intrusion. In granite gneisses which show a pegmatitic texture, as in the Hoadley Point, Connecticut, gneiss, the bands of quartz and porphyritic feldspar may be an inch across and separated by continuous sheets of biotite.

In gneisses whose lamellar character is due to mashing and recrystallization, the emphasis is put here not merely upon the presence of crystallizers, but upon their passage. The crystallizers are to be interpreted as the rising emanations from deeper seated sources.

Development of Lit-par-Lit Structure by Force of Crystallization.

Lit-par-lit injection is that form of magmatic intrusion which takes place where the magma has soaked into a highly foliated roof rock and has resulted in all grada-

tions of composition from unaltered country rock to pure igneous rock. The penetration of the magma has not been accomplished by the massive invasion of appreciable viscous fluids, but is more suggestive of capillary action and intercrystallization. The thinnest of parallel mica laminæ may be traced throughout their length without showing such crumpling as even the inertia of the least viscous fluid would have given them if the invading magma had all been fluid. From sheets of magma and of schist which are only of crystal thickness, all gradations in width may be traced into wide bands of country rock or equally wide dikes of pegmatite or granite. The phenomena are extensively displayed in Connecticut, and the writer is more particularly familiar with the large field of mixed rock known as the Waterbury gneiss, extending through western Connecticut from Torrington to Derby. Doctor G. O. Smith and the writer studied this area in 1906, and came to the conclusion that the best way for making field maps was, knowing the pure types of cover rock and granite, to estimate for each outcrop the ratio of the two. This would give data for deciding where, and on what basis, formation boundaries should be drawn.

[Doctor Fenner[25] has described the same features in an independent study of the highlands of New Jersey. He clearly shows that the hydrous magmatic emanations or differentiates may precede the magma *lit-par-lit* by penetrating small pores where their lower viscosity allows them much more rapid movement than the main magma. This penetration of solutions makes the rock more like magma in composition, as well as conducting magmatic heat in advance of the magmatic invasion, until finally, if the magma advances, it reaches a rock so modified that one would expect it to be readily assimilated.]

The great bursting power of freezing water is well known, even when acting between surfaces such as joint planes, which permit free ingress and egress to the water. Becker and Day[26] have discussed this power as exhibited by other crystals. The phenomena of feldspathization, as shown in *lit-par-lit* structure, suggest that for such mixed gneisses this factor should be elevated to a first place. A solution permeates and passes through a foliated rock. The temperature falls as the solutions flow outward. The

[25] C. N. Fenner, Jour. Geology, 22, 594 and 694, 1914.
[26] G. F. Becker and A. L. Day, Jour. Geology, 24, 313-333, 1916.

saturation point is passed and crystallization begins on particular foliation planes. Mica has mostly been left behind in the magma, so the growth is principally by the addition of quartz and feldspar. The continuation of growth requires the pressing apart of the walls of each lamina by the force of the growing crystals. Unevenness of crystal growth keeps the whole in a sufficiently porous condition to permit the passage of more fluid. The expansion on many planes requires some mass movement of the rock, resorption elsewhere, condensation, mashing, or crumpling. A slight accession of heat and gases or pressure in one locality will turn crystallization into solution and resorption, permitting more readily the expansion of other and adjacent parts by intercrystallization. Rock flowage under such conditions must be relatively easy, since the whole is within the temperature range of crystallization and slight changes of equilibrium will turn the balance from one side of the equation to the other. The chief loss of energy is that carried off by the solutions whose continuous passage is needed to maintain the critical conditions.

The different minerals are doubtless quite differently susceptible to stress-differences. Although under normal conditions of great pressure but no stress-differences, the micas crystallize before quartz and feldspar, if stress-differences become great, then recrystallization of mica appears to proceed more readily than that of feldspar and quartz. The pressing apart of the magma walls may thus result in a schistosity imposed while the intercrystallization is still going forward. The process of infiltration proceeds until any degree of granitization has taken place.

The process is not marked by the development of vein structure; rather each minute seam is like a pegmatite or granite in texture. The crystallization is, therefore, not so much against the walls as in between the walls. As long as the solutions are passing, they are impelled by the greater pressures of the magma below, and the excess pressure over that of the surrounding country rock at any place is expressed by the hydrostatic head needed for overcoming the frictional resistances to flow. This hydrostatic head is an essential factor, for it means that the fluid can support the pressure of the growing crystals and these do not need to resist porosity by mutual pressure at their points of contact. A pegmatite

vein may therefore hold a porous texture and yet be solid during the time of growth, in much the same way as a porous sandstone may be strong and yet serve as a passage for circulating waters. The difference, however, is that the hydrostatic head of the meteoric waters is less than that of the sandstone, with the result that the recrystallization of the sandstone eliminates the porosity and develops a quartzite. In the pegmatite, on the contrary, the porosity would be maintained as long as the country rock could yield before an excess of hydrostatic head from the magmatic emanations. The last stages in the development of the crystallization would be a final elimination of the porosity. It would seem that this is a rather fundamental theoretic principle whose existence it is necessary to postulate in order to obtain a workable understanding of the phenomena of regional granitization as shown by *lit-par-lit* structure.

DEVELOPMENT OF BANDED ORTHOGNEISSES AS A RESULT OF SUCCESSIVE INJECTIONS.

The foliation of the granite gneisses was once looked upon as an evidence of sedimentary origin. With the recognition of their igneous nature and the evidences of later mashing, a contrary interpretation very generally came in, regarding the foliation as wholly due to rock flowage in the solid state. Observations began to multiply, however, which showed that a very appreciable portion of gneisses owed their parallel structure to flowage while in the fluid or partly fluid state—the protoclastic structure of primary gneisses. This is contrasted with what Becke called the crystalloblastic structure—that developed by rock flowage—in the true compression gneisses. Adams especially has shown the importance of deformation during crystallization for the Laurentian gneisses, and Leith in his Structural Geology calls attention to the dominance of protoclastic gneisses.

It is desired here to emphasize a somewhat different phase of the subject which may be called intermittent injection and crystallization in batholithic roofs. It seems to be associated especially with regions under differential crustal compression, and gives banded orthogneisses.[27] It may grade from the previously described

[27] [The nomenclature of the gneisses is in danger of confusion. It is well, following Van Hise, to make the term gneiss one of purely structural significance. Rosenbusch includes in the main division gneisses of igneous

masses show no or almost no kinship in chemical composition with the surrounding walls. Such assimilation as does take place must normally be abyssal, as the result of the subsidence of blocks cut free by the roof dikes, the process which Daly has named stoping. Daly, however, puts the emphasis of stoping on marginal shattering and brecciation into fragments up to 10 meters in diameter. The writer, on the other hand, looks upon this as chiefly a decadent feature of magmatic action, and regards the cutting free of large roof blocks by intersecting dikes and sheets of high fluidity as the chief feature which marks magmatic advance by stoping.

The next point to be noted is that the batholiths quite commonly reach their farthest limit before marked differentiation begins to set in, as shown by the dioritic rims chilled against their borders. Quite often, however, the later granites break through to higher levels in the crust, but such are often intrusive bodies, as great sheets, dikes, or chonoliths, rather than broad batholiths. The mode of batholithic rise at great depths can not be known by direct observation, and what is here considered deals only with the phenomena exposed by erosion. The roofs of batholiths are greatly deformed, showing especially domal and quaquaversal forms. This of course permits greater upwellings of the magma, is distinct from stoping, and simulates the results of laccolithic intrusion.

How is the integrity of the roof preserved? In regions of orogenic batholiths it would seem that a potent factor must be the advance granitization in the cover. The rising gases carry magma with them to the cooler regions and will seek the stretching zones of the cover. Here they precipitate their burden and pass on. Dikes intruded high into the cover likewise will become chilled and their flow tends to become checked as by the coagulation of the blood in a wound. The precipitation of quartz and feldspar by these means may go on to a large extent and permit of adjustments of the cover to the hydraulic and hydrostatic forces imposed from below. From time to time come into operation also extraneous thrusting forces, controlling the orogenic nature and modifying the results which would be given by the rise and cooling of the magma alone.

In these relations of batholiths to covers, there is much which is unknown, but the purpose here is not to follow

out this line of research; but on the contrary merely to show that the metamorphic phenomena associated with the roofs of orogenic batholiths, in order to be understood, must be analyzed into the two phases of the rise and decadence of magmas.

Alternation of Injection and Mashing.

This phenomenon may be made more impressive by the description of certain specific formations rather than by dealing wholly in general statements. The writer has studied these relations especially in the Laurentian Becket gneiss of southwestern Massachusetts and in various Paleozoic batholiths and intrusions in Connecticut.

The Becket gneiss has been described by Emerson,[30] but the following statements are planned to bring out in brief form those features significant under the present topic. The dominant phase is a biotite granite gneiss, almost massive in some localities, in others strongly banded. The gneissoid phases of this rock show considerable granulation and only a moderate amount of recrystallization. On a fresh fracture the rock shows a grain like granulated sugar, and the biotite is scattered with a pepper and salt effect, not markedly segregated into planes. On cliff faces the biotite weathers out, the surface becomes white and siliceous and gives rise to the name of white gneiss. The banding is probably mostly due to non-uniform compression and flowage during crystallization, though considerable granulation after complete solidification seems to have occurred.

From this rather uniform facies of the gneiss there are passages into areas of highly variable banding, the banding being of all scales of magnitude from a few inches to hundreds of feet. The bands consist of amphibolites, hornblende, diorite gneisses, biotite granite gneisses, acidic granites, and pegmatites. The hornblende layers in many instances are intimately associated with bands of pegmatite and aplite, feathering into the acidic material and swelling into lenses in a way to show that the two were simultaneous differentiates rising through the foliated rock and crystallizing separately from an aqueous solution. The amphibolite, often developed as a ribbon gneiss, is most abundant in contact zones against

[30] B. K. Emerson, U. S. Geol. Survey, Bull. 159, 1899.

and in the included metasediments, and as such zones has been described by Emerson as the Lee gneiss. He considers that both differentiation and some solution of sediments have occurred, but rather broad areas of these rocks are found without visible relations to contact rocks. The relations, however, all permit these amphibolitic ribbon gneisses to be looked upon as roof rocks to the Laurentian batholith. They belong in general to an early stage, they average more basic, corresponding to the marginal basic facies so common in batholiths, and they show intermittent injection. The presence of much water-vapor is the natural explanation of many of the associated features.

Cutting the foliated and granulated biotite gneisses and amphibolites are younger bodies of massive granite which range from biotite granites to aplites and pegmatites. Dikes of these are well displayed in the railroad cut at West Norfolk, Connecticut. These intrusions are later than the regional metamorphism. It is possible that they might be much later, but their associations in the Becket areas, their acidic character, and the analogy with the other localities to be described suggest that they are more probably parts of the same igneous cycle, that the regional metamorphism proceeded during the same period, but had spent its force before the last intrusion of granites.

The Paleozoic batholiths of Connecticut are much more satisfactory for study, since their structural relations with their roofs are widely revealed.[31] The outcrops of the batholiths are elongate or rounded forms. Around the margins many show a basic border rich in hornblende and biotite. As in the Becket gneiss, the basic border shows a highly variable and banded character. A very considerable degree of mashing is to be observed, as shown by the degree of crumpling of the oldest cross-cutting pegmatites. The oldest gneisses are biotite granite in composition, and the gneissic structure is well developed. The basic border is a differentiation phase of these, as shown by the uniformity with which it constitutes the margin and intrudes the surrounding sediments. The pegmatites in this zone are of two ages,

[31] For detailed descriptions of the Connecticut formations, see W. N. Rice and H. E. Gregory, Manual of the geology of Connecticut, Conn. Geol. Nat. Hist. Survey, Bull. 6, 1906. Also T. N. Dale and H. E. Gregory, The granites of Connecticut, U. S. Geol. Survey, Bull. 484, 1911.

the earlier showing much mashing, the later showing little or no deformation. On the west side of the Connecticut, the biotite granites and granodiorites occupy large areas, are distinctly gneissoid, and are intruded by the white Thomaston granites. These are almost free of dark minerals, are fine-grained, and only slightly gneissoid. They form some fairly large bodies, but most of them form thick dikes or sheets rather than great batholiths. On the east side of the Triassic valley, the red biotite Branford or Stony Creek granite is younger than the biotite granite gneisses. An excellent exposure in the railroad cut east of Stony Creek shows how it has shattered and intruded the older gneiss. In the vicinity of the Stony Creek quarries, blocks of the older rock from one or two feet up to many feet in diameter are suspended in the younger granite. The latter shows marked schlieren and pegmatitic structures, but here is almost uncrushed. Toward Leete Island, however, the younger granite passes into a coarse banded gneiss with marked pegmatitic habit. Large porphyritic crystals of feldspar have developed between the biotite laminæ, and the whole is suggestive of strong deformation during and following the period of primary crystallization. Aplite dikes cut the coarse gneiss but have themselves been affected by the pegmatization. Farther east in Connecticut, Dale has described the dikes of commercial granite which cut the older gneissoid granites and states that the latter are in general younger than the gneisses intruded into the sediments. It is possible that the granites in the east are of different age from those in the west, but within each province the evidence shows a genetic relationship between the sequence of intrusives. This evidence is found in the space relations and in the chemical relationships. The older magmas were of the composition of biotite granites or granodiorites, and developed basic borders with pneumatolitic structures. Within these masses the younger granites were commonly restricted. If the latter belonged to a wholly different cycle of igneous activity, they would not be expected to show this space relation but would be as likely to break across the old margins and into the surrounding rocks. The composition also follows the usual law of differentiation and points to the younger granites being the last phase in the differentiation of the same magmas. The date of most

of this igneous activity would seem to be late Carboniferous, as the sediments of the latter age in Rhode Island and Massachusetts have been intruded and metamorphosed. Warren and Powers[32] hold, however, that some of the eastern Massachusetts granites belong to the Devonian orogenic movement.

The relation between the different intrusives and the stages in regional metamorphism in eastern Connecticut has been well presented by Loughlin.[33] Here the intrusion of a gabbro laccolith preceded the regional metamorphism, since the blocks of wall rock included within the resistant gabbro show as angular blocky fragments of hornfels, whereas the adjoining country rock is now highly foliated. The granite of the same area appears to have been intruded in association with the regional mashing and to have completely crystallized before it ceased. The alaskite, the youngest rock, completed its crystallization after the closing of the period of rock mashing.

The conclusion of first importance which a statement of these relations leads up to is that the regional metamorphism is intimately related to the batholithic intrusion. Deformation and metamorphism of the sediments began before the intrusion of the granites, but had not begun before the intrusion of the Preston gabbro. It ceased before the last upbreaks of the acidic phases of the magma. This conclusion applies to all southern New England and apparently much the same relationship between intrusion and metamorphism existed in the Laurentian invasion.

Furthermore, both igneous activity and crust movements are known to be of a periodic character. The suggestions of this study are that in regional metamorphism there is a certain intimate rhythm between the two. The phenomena of injection and mashing are alternating phases in a general period of intrusion and metamorphism. When the pressures in the upper part of the magma come to exceed the lateral pressure on the cover rocks, the advance gases, insinuating themselves on foliation planes, widen them out and permit the ascent of the regional magma. This favors mashing of the adjacent region. But when the yielding of adjacent parts of the crust concentrates the lateral compressive

[32] Personal communication.

[33] G. F. Loughlin, U. S. Geol. Survey, Bull. 492, 1912.

forces once more upon this region, it is still heated to near the temperature of crystallization; rock mashing and recrystallization take place in it. The development of differentiation to its final stages gives an acidic magma in the upper part of the reservoir. The escape of the gases in whose presence only this magma can remain molten hastens the crystallization to great depth. The crust is once more strengthened, rock mashing becomes ineffective, the period of orogenic activity as marked by igneous intrusion and dynamometamorphism has come to a close.

ART. XVII.—*The Post-Glacial Terraces of Anticosti Island;* by W. H. TWENHOFEL and W. H. CONINE.

INTRODUCTION.

There are probably no more impressive features in the physiography of Anticosti Island than its terraces. Like stairways for giants, they begin at the level of the sea—possibly below sea-level—and continue into the interior as far as the eye is able to follow. The highest measured exceeds 400 feet. The cliffs or steep slopes which front them vary greatly both in height and in extent. In places a terrace may have a width of a mile or more; in other places it narrows to disappearance, with its cliff or front slope merging with the cliff or front slope of one of those above. The places of greatest width are about the indentations of the coast; the places of least width are on the salients.

Anticosti Island is a cuesta with the escarpment facing north, the dip slope facing to the south. The northern channel occupies the inner lowland. The trend of the island is not parallel to the structure nor is the strike of the strata identical with the trend of the island. Progressively younger strata are met in proceeding eastward along the north side, progressively older strata in going westward and eastward from Southwest Point along the south side.

The asymmetry of the island's surface with respect to its north and south slopes is reflected in its terraces. On the south side, some of them are several miles wide, and to reach the summit of the highest, it is necessary, in most places, to go somewhere near the middle of the island. On the north side, the highest observed terrace may be reached in many places within a couple of miles

of the sea and there are a few places where it is within a mile. The greater width of the terraces on the south slope lessens the impression they make and, except where a high headland reaches the sea, not more than three or four may be seen in most localities; on the north side, on the other hand, the terraces can not fail to attract the attention of even the most casual observer and there are many places where more than a half-dozen may be seen.

At the time of the senior writer's first visit to Anticosti in 1908, the terraces were noted—it would have been impossible not to have seen them—and a few estimates were made as to their number and heights. On the second visit in 1919, a consistent effort was made to obtain exact data relating to them and Mr. Conine was instructed to give all the time at his disposal to this end. In addition, measurements were made at many places by the senior writer and other members of his party. The result is that elevations and width of terraces have been obtained at several dozen localities of which only a few are shown in the diagrams. Measurements were ordinarily made by hand leveling and pacing, but in a very few instances heights and widths were estimated. Wherever possible, the nature of the materials on the surfaces of the terraces was determined. This could only be done, however, on the edges of cliffs and about the roots of upturned trees, neither of which is everywhere present.

Collection of data relating to the terraces is simple, but not always easy; nor are the results obtained altogether accurate. As soon as one leaves the beach, he finds himself in an almost impenetrable forest through which he rarely can see more than a couple of hundred feet at most. The problem for most of the terraces was confined to the obtaining of their heights and widths at localities which appeared likely to give the most accurate results. Except for the lowest terrace, little effort was made toward correlation, as this is impossible except by the actual walking out on each terrace entirely around the island, and to do this for each one, or for any one, was out of the question.

Detailed Description of the Terraces.

The sea-level terraces.—The lowest exposed terrace of Anticosti is the one whose width is at present being ex-

tended by the work of the waves. This is known as the "reef" by the people of the island and by the sailors of the Gulf. Its presence is a menace to navigation and it renders many parts of the coast of Anticosti inaccessible from the sea except to the smallest of boats. Its width varies from nothing to about three miles, the greatest width being on the south side at the mouth of Dauphine River, but it is almost everywhere present to some degree except in those bays which have barrier beaches about their heads as is the case at the mouths of Jupiter River, Salmon River, Fox River, etc. On the south side there are not many places where the reef does not have a width of at least an eighth of a mile, and a quarter- to a half-mile width is an extremely common occurrence. On the north side the reef is less marked than on the south, but even there it is commonly from a sixteenth to an eighth of a mile wide.

The reef shows little other than barnacle- and seaweed-covered rocks. Pebbles are generally wanting except at the shore, where they are apt to be in quantity unless the rock of the coast is composed of material from which they could not readily be derived. Were the shells and seaweeds removed from the reef, there would be little or nothing present to show that it is of wave-cut origin; morever, it is probable that if the waves should cut entirely across the island so as to develop a reef over the entire extent of its present area, there would be no conglomerate to show the wave-cut origin, and, were the reef then submerged, there would be no basement conglomerate to mark the unconformity, but sands and muds would rest directly across the truncated edges of the limestones, shales, and sandstones which constitute the rocks of the island.

The terraces above sea-level.—The terraces above sea-level are tabulated in the list which follows. It is probable that the elevations which are given contain some error for all terraces above the eighth, this being a necessary consequence of the method of measurement and the conditions under which measurements were made. Another factor introducing an error is the fact that every terrace is covered with vegetable mould and peat of which the thickness was not always determinable. So far as possible, however, an estimate has been made and a deduction allowed therefor.

Terraces whose elevations are considered most accurate are designated by an asterisk. Those which have been observed in the greatest number of places are the 1st, 2nd, 3rd, 6th, 7th, and 10th. For statement of elevation at the various localities, the reader should consult the diagram (fig. 1).

The 5 to 6-foot terrace has been seen at hundreds of localities and in many places it is fronted by a littoral barrier which in some instances is 12 to 15 feet above tide-

Fig. 1.—Profiles of terraces at various localities. Each vertical space equals 25 feet, each horizontal 25 feet.

1, 5-6 feet*; 2, 10-13*; 3, 20 feet*; 4, About 29 feet; 5, 40 feet*; 6, About 51 feet*; 7, 60-65 feet*; 8, 74 feet; 9, 85 feet*; 10, About 95 feet; 11, 105 feet; 12, 115 feet; 13, About 120 feet; 14, About 130 feet; 15, 145-150 feet; 16, About 180 feet; 17, 210 feet; 18, About 300 feet; 19, 344 feet; 20, 380 feet; 21, 409 feet; 22, 442 feet.

level, thus attesting to the power of the waves on those portions of the coast. This terrace is ordinarily not of great width, but it is commonly a hundred or more feet wide and there are places where it approaches a width of a half-mile. On its landward margin there are not uncommonly hooded or overhanging cliffs at the feet of which are talus slopes related to the cliffs in the manner shown in figure 2, which represents the elevated cliff between West Point

and English Head. On the apices of most of the headlands, this terrace is cut away, but on their sides there are talus heaps overhung by the cliff, and these rest on the top of the terrace. It is probably the most continuous terrace of the island.

The 10 to 13-foot terrace is that on which most of the moorland of the south shore is built, and its present varying height (16-17 feet) is largely due to the differential accumulation of peat on the top. Over extensive stretches of the south coast this terrace is several miles wide and it is probably the widest of the island. A 20-foot terrace has been observed in many places, and also

FIG. 2.—Diagram of the "reef" and the first and a higher terrace between West Point and English Bay. The top of the barrier is about 10 feet above high tide-level. The upper terrace is about 40 feet high. The truncated strata beneath the barrier make the floor of the lowest terrace above sea level.

varies in height due to differential accumulation of peat. The very high terraces are among those best shown and they are also quite wide. On the north side they are generally fronted by a very steep slope, for instance, Macasty Mountain is faced by a slope difficult to climb—landslides having occurred upon it—and its summit is very flat and carries gravel resembling that existing on the present beach. The terrace here is 409 feet above sea-level.

The land above the 442-foot terrace, the highest measured, is also very flat and of terrace-like aspect. Taking observations as to heights and widths on these higher areas was, however, so difficult that none was attempted, as it was clear that any data that could be obtained would

contain so much error as to be of little value. Gravel which appears to be of beach origin lies on this higher land wherever it has been seen.

Origin of the Terraces.

In essentially every locality the terraces truncate the structure. On the north side the outer margins are cut on older rock than the inner margins and eastward they truncate younger rock than westward; exactly opposite conditions, however, obtain on the south side. They are cut indiscriminately over weak and strong beds. These facts eliminate any possibility that the terraces may be of structural origin.

Most and probably all of the terraces bear gravel which is of beach origin and such gravel has been observed on the highest measured terrace. Bowlder beaches or lines have not been seen, but such are not likely to be present, as bowlders are not common on the present coast. Such gravel as has been observed is like that of the present coast except that on the higher and older terraces it is more or less roughened by solution. Shell-bored rocks have been found up to at least 85 feet above sea-level in the region between Ellis Bay and English Bay. Dr. Joseph Schmidt, who lived on the island for many years, considered that "marine water had covered the whole of the island within the late geologic past."[1]

Most of the terraces and probably all of them are fronted at some places by steep cliffs or slopes, and where the cliffs are well preserved, they are such as could have been developed only by the waves. Such cliffs of course are most common in connection with the lower terraces. These facts are considered proof that the terraces were cut by the waves. The fact that gravel of beach origin has not been found everywhere can not be adduced as an objection, as it does not occur everywhere on the present beach, the major portion of the reef being without it.

Time of Origin of the Terraces.

In this connection it is necessary to consider the glaciation of the island, the Champlain submergence, the deposits of post-Champlain time, and the age of the river valleys. The facts developed from the examination of these

[1] Joseph Schmidt, Monographie de L'Ile d'Anticosti, Paris, 1904, p. 94. Free translation.

features and events will furnish data from which to draw a conclusion relating to the time of terrace development.

Glaciation of the island.—During the Ice Age, glaciers which originated in Labrador covered the island,[2] as is proved by the abundant presence of glacial erratics ranging in size up to many tons. Many of these are composed of labradorite, which could hardly have originated elsewhere than on Labrador. Till appears to be rather rare. At many points about the shores and along the rivers are stratified deposits of sand, gravel and clay, such having been observed up to elevations of 100 feet above sea-level in the cliffs of the shore. Unstratified glacial gravel was seen in the bed of the Vaurial River up to 12 miles from the sea at an elevation of 322 feet (stadia measurement). Striated and soled pebbles are extremely common in these deposits. Except for such of them as are unstratified they are not of the time of the Ice Age so far as deposition is concerned.

On the Vaurial River, glacial striæ were seen on the limestone in place, the direction being S. 24° W. and the elevation 35 feet (stadia measurement). Glacial striæ were also seen at Cormorant Point in two places, at one of which they have the direction S. 20° W., and at the other S. 3° W. Schmidt has noted the occurrence of striæ at Cape River which have a direction from northeast to southwest.[3] These facts are sufficient to prove that the Pleistocene glaciers covered the island. They seem to have in no way modified the terraces, and the latter therefore appear to be younger than Pleistocene glaciation.

The Champlain submergence.—Clays and sands containing an abundance of *Saxicava rugosa* and *Mya truncata* have been observed at Ellis Bay at an elevation of about 20 feet above sea-level, and have also been seen at Otter River and Jupiter River, at the latter place being estimated to be 30 to 40 feet above sea-level. On the north side they are known to be present on the brook which empties into Little Macasty Bay, and it is probable that similar clays and sands occur at many other places. It is obvious that these deposits were made at a higher stage of sea-level than the present one. They are truncated by all the terraces up to the height of their occur-

[2] T. C. Chamberlin's map of the great Ice Age shows the island to have escaped glaciation.

[3] Joseph Schmidt, op. cit., p. 89.

rence, proving that these terraces have been formed since Champlain time.

Deposits of post-Champlain time.—At many points along the coast are the stratified sands and gravels to which reference has been made. At Southwest Point these deposits are truncated by the 65-foot terrace, at Caplin River an 85-foot terrace is cut across them, and at Cape Ann the 74-foot terrace does the truncating. At the last named place the many shells of *Mytilus edulis* and *Mya arenaria* occurring throughout the deposit—species now living in abundance along some portions of the shores of the island—show that these deposits are of an age younger than those laid down during the Champlain submergence. The highest point where these gravels have been observed is about 100 feet, and every terrace up to the height of their observed occurrence passes from them to bed rock without appreciable break in flatness.

Age of the river valleys.—The river valleys are of two distinct types. Nearly all the smaller streams flow in rock-floored, narrow valleys and the greater portion of these reach the sea over rapids or a fall, the streams not being able to cut downward as rapidly as the sea cuts landward. Other streams have wide valleys and flow over floors of gravel and sand, attesting to the presence of an older valley floor beneath. The latter type is illustrated by parts of the Caplin, Vaurial, Jupiter, Fox, Otter, and Salmon River valleys, which are in that stage of the erosion cycle verging very closely on maturity. The Caplin River has a broad flood-plain for such a small stream and as a general rule the valley slopes are gentle. Near the mouth, however, the valley narrows and the stream flows to the sea between high cliffs, which are composed of bed rock, but behind which there are cliffs composed of glacial and stratified gravel. This suggests that the stream has made a new entrance to the sea, and as the shore to the west consists of gravel cliffs for fully a half mile it is probable that the older valley lies hidden there. These older valleys are of pre-glacial origin, as shown by their aspect of maturity, the glacial deposits which are in them, and the glacial striæ which have been seen on the Cape and Vaurial rivers. As no Tertiary deposits have been seen in any of them, it is assumed that this region was as high in pre-Glacial time as it is at present, with the probability that it was somewhat higher. The

streams of the first group are probably in large part post-Glacial.

Conclusions as to the time of formation of the terraces.—The terraces are shown along the valley walls of each type of stream, but are not present on every stream, particularly those of youthful appearance. Many are known to truncate Glacial and post-Glacial deposits, and beach gravels have been seen on essentially every one of them. Since the island was glaciated, the glaciers would have removed the gravels, but might also have carried others upward from the beach. Till is generally absent, but its removal could have been most extensively and completely accomplished by beach washing. The age of the lower terraces is unquestionably determined. If the higher terraces be Tertiary, they would appear to be older than the larger river valleys, but they are shown on the sides of most of the latter, and are therefore subsequent. The facts lead to the conclusion that all of the terraces are post-Glacial.

The question may be approached from another angle. How long a time would be required to cut these terraces? How long a time is required to cut a terrace a mile wide on the rocks of the island? Wave erosion on Anticosti appears to be very rapid. The rock as an average is not particularly strong, is much jointed, and there is much frost wedging. At Heath Point, Mr. Christopher Hubert, the light keeper, pointed out a road which had been moved twice between 1909 and 1919, and the rock at that place, if anything, is somewhat more resistant than the average. The estimated width eroded in the ten years is 20 feet, or a mile in a little over 2500 years, and at this rate, to cut the present sea-level terrace at its greatest width would have required about 7500 years. As the average width of this terrace is not much more than a mile, it may be assumed that about 3000 years were required for its development. On the south side of the island the gradient of the surface is gentle, and the surface low, so that in the cutting of any one of the terraces the quantity of material to be eroded and transported was not great, thus permitting the terraces to develop to great width. On the north side, erosion is just as easy, but the elevation above sea-level is so much greater that a move of one foot inland required the removal of from five to forty times as much material as is the case for a movement inland of the same

amount on the south side. A longer time would, therefore, be required to cut an equal width of terrace on that side, hence their lesser width. Such was the case in the development of every one of the terraces; with the possible exception of the highest, which probably began to develop when no high land existed. If each uplift meant the development on the south side of a terrace with an average width of one mile—probably a far too large assumption, as many of them are known to have reached a width of only a fraction of that figure—the time for the development of the twenty-three terraces would have required as a maximum not above 70,000 years. This approaches the estimate of time which has elapsed since the Ice Age.

There is still another line of evidence which has not been mentioned. On the Mingan Islands to the north are many rocks which were called "flower-pot" rocks by Richardson.[4] These are stacks which were developed by the waves, and all of them are at elevations the highest of which probably does not exceed 50 feet. On the top of West Cliff there is also a stack-like structure at a height of a little more than 400 feet above sea-level. Had this structure been there in Glacial time, with its present size, it would most certainly have been shoved away, unless the glaciers did not rise to this height, a possibility which the bowlders lying at elevations almost as high strongly negate.

All lines of evidence hence converge to the conclusion that the terraces were developed in post-Glacial time.

If the terraces are of the age inferred, it follows that there has been a negative movement of the strand-line exceeding 400 feet since the period of glaciation. The existence of the terraces shows that the periods of uplift have been separated by times of relative stability. The hooded cliffs and the "flower-pot" rocks in the Mingan Islands to the north show that the last uplifts have been comparatively recent, otherwise these features would have been obliterated under the strong frost action which prevails on these islands and on Anticosti. Anticosti is said by the people of the island to be rising at present, as they tell of harbors being no longer accessible to boats which thirty years ago found easy entrance. Mr. Alfred Malouin, who has lived on the island for around forty

[4] James Richardson, Geol. Survey, Canada, Rept. of Progress for the years 1853-1858, p. 242, 1857.

years, states that he is confident that there are parts now above water which were submerged when he first came.

Correlation with Terraces Elsewhere.

It is extremely difficult to correlate any of the terraces of the island with those of other parts of the St. Lawrence. One may be certain that a terrace of the same time of development is present on both the south and the north sides of the Gulf, but to state the identity in time of development needs far more work than has yet been accomplished. Goldthwait[5] has described a 20-foot terrace and sea-cliff about the lower St. Lawrence, and perhaps the 20-foot terrace of Anticosti is its correlative.

At Ottawa, Johnston[6] has described old shore-lines up to about 690 feet sea-level—more than 200 feet higher than the highest terrace of Anticosti—and has found stratified clays with fossils up to 510 feet. Many beaches are present and some of these must certainly correlate with those of Anticosti, but it is altogether impossible to state which are synchronous.

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[5] J. W. Goldthwait, this Journal (4), 32, 291-317, 1917.
[6] W. A. Johnston, Geol. Survey, Canada, Mus. Bull. No. 24, 6, 1916.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Devitrification of Glass*—It has been found by Albert F. O. Germann that the well known peculiar behavior of many samples of old glass upon heating before the flame is a surface phenomenon, and that such glass can be restored to a workable condition by simply washing it with dilute hydrofluoric acid in order to remove a thin film of the surface. This observation is an important one, as it gives a method for utilizing old glass and for repairing old glass apparatus. It is the author's opinion that this surface change is due to the absorption of moisture, but the matter does not appear to be perfectly simple, because it is mentioned that a tube which devitrified badly at first showed no tendency to behave in this way after having been exposed casually to laboratory fumes for more than six months. Perhaps the absorption of carbon dioxide takes part in the devitrification since this might be removed by the action of acid fumes. H. L. W.

2. *A Substitute for Thoulet's Solution.*—A. Thiel and L. Stoll mention the employment of heavy solutions for the determination of the density of solids, by floating and sinking, some of which solutions are mixtures of organic liquids and others are aqueous solutions. Among the latter the best known are potassium mercuric iodide (Thoulet) and barium mercuric iodide (Rohrbach). For organic compounds the aqueous solutions are practically the only ones employed, and for most of these solutions of calcium chloride with a specific gravity up to 1.4 answer the purpose, but the authors had occasion to use a heavier aqueous solution and found that lead perchlorate gave solutions up to a density of 2.6. It is more agreeable to use than the mercuric solutions, the solution is mobile and it does not attack the skin to the slightest degree. It can be prepared cheaply by saturating commercial perchloric acid with lead carbonate and evaporating to saturation. This solution is evidently a very satisfactory one for use with many organic compounds, but unfortunately it could be used only with the lighter minerals, since its maximum density is slightly below that of quartz.—*Berichte*, **53**, 2003. H. L. W.

3. *Priestley in America, 1794–1804;* by Edgar F. Smith. 12mo, pp. 173. Philadelphia, 1920 (P. Blakiston's Son & Co.).—Professor Smith, in writing several recent books, has rendered valuable service to the early history of chemistry in America, and now he has increased this service by presenting the little book under consideration. From contemporary newspapers, documents and books, he has found much interesting information concerning the life and activities during his exile in America of this noted discoverer of oxygen. It appears that Priestley's activi-

ties in Pennsylvania were largely connected with philosophical and religious work, but nevertheless he did a considerable amount of laboratory work and wrote frequently in favor of the phlogistic theory, to which, as is well known, he adhered to the end of his life, although his own discovery of oxygen had paved the way long before for the modern views of oxidation. The book presents the subject very well, and is to be recommended to those who are interested in the history of chemistry. It mentions some important incidents, such as the acquaintance of Priestley with George Washington, and an invitation to him by the latter to visit his home at Mount Vernon. H. L. W.

4. *Introduction to General Chemistry;* by H. COPAUX. Translated by HENRY LEFFMANN. 12mo, pp. 195. Philadelphia, 1920 (P. Blakiston's Son & Co.).—This is a clear and concise exposition of the principles of modern chemistry as recognized today by the leaders of the science. It should be a valuable guide to those who wish to obtain a clear view of the subject. Besides presenting the older fundamental laws and theories of chemistry. the book discusses the more modern topics, such as radioactivity, the structure of the atom, the phase rule, etc. A short appendix, dealing with hydrogen-ion concentration, has been contributed by the translator. H. L. W.

5. *A Text-Book of Organic Chemistry;* by E. DEBARRY BARNETT. 8vo, pp. 380. Philadelphia, 1920 (P. Blakiston's Son and Co.).—In this text-book from England the author has described the important classes of compounds both aliphatic and aromatic. He has generalized, however, wherever possible and has thus avoided the introduction of much specific descriptive detail, which is always troublesome to the beginner. General theories have been grouped under one heading in order that they may be more readily referred to when occasion requires. Several pages have been devoted to a description of the original literature and its use. This is indeed worthy of mention since the use of the journals is an essential part of every organic chemist's training and attention should be paid as soon as possible to this phase of the student's work. The book gives a very favorable impression, but unfortunately many errors in typing have escaped the notice of the proof readers. J. J. DONLEAVY.

6. *Comparison between wave lengths of solar and of terrestrial origin.*—The relativity theory of Einstein offers a prediction that the wave length of light emitted by an element upon the sun should be about two parts in a million longer than that of the same element upon the earth. Such indications of a difference as have hitherto been published have not been accepted as altogether valid. A recent determination by A. PEROT justifies the existence of a real difference. His investigation was made upon the second head of the cyanogen band, 4216, which is particularly favorable for observation on account of its isolation in the solar spectrum. Its wave length was taken as 4197 A, and the measurements made by a spectroscopic interferometer.

As the vapors producing the absorption appear to occur in the more elevated regions of the solar atmosphere they must be regarded as subject to a relatively low pressure. M. PEROT accordingly used as his comparison source a carbon arc under a pressure between 22.5 and 30 millimeters of mercury. As the result of his investigation he states that he was able to determine that the difference sought lay between 2.2 and 1.6 parts in a million, an interval which contains the Einstein number.—*Bull. Soc. Fr. de Phys.*, **147**, Dec., 1920.

7. *The Imaginary in Geometry;* by J. L. S. HATTON. Pp. VI, 215. Cambridge, 1920 (Cambridge University Press).—The author's purpose is to develop a generalized conception of geometry and of space in which each of the three coordinates is regarded as a complex quantity of the form $x + ix'$, $y + iy'$, $z + iz'$. By adding to the axioms of real geometry, but employing its principles and methods, the well known theorems of plane and projective geometry, of trigonometry, and of the conic and conicoid are extended and generalized. It is a book for geometricians only. F. E. B.

8. *The Principles of the Phase Theory;* by DOUGLAS A. CLIBBENS. Pp. xx, 382, 198 figures. London, 1920 (Macmillan & Co.).—This book on heterogeneous equilibria does not attempt to give a general survey of the whole field. It deals exclusively with systems which contain no vapor phase, the so-called "condensed systems," with the further limitations that only one liquid phase may be present and no solid solutions. Moreover, the practical illustrations considered are all cases of equilibrium between water and salts, though the theoretical principles involved are, of course, applicable to all condensed systems.

Even with these limitations, the field to be covered is a large one, but they make it possible for the author to deal quite briefly with binary systems, and to devote the major part of the book to the more complicated and less familiar systems of three, four and five components. A final chapter deals with graphical methods for determining, from the compositions of the phases present at an invariant point, what reactions may occur there.

The book is good both in plan and execution. There is no conspicuous originality in treatment, but in a field so well developed it could hardly be expected. The author's style is clear, and the systematic and exceptionally thorough way in which the behavior of each different type of system of a given group is discussed before taking up concrete cases, is worthy of special mention. As the treatment is non-mathematical the book should be suitable for the use of readers who are unfamiliar with the subject. R. G. V. N.

9. *Lessons in Mechanics;* by WILLIAM S. FRANKLIN and BARRY MACNUTT. Pp. XI, 221. Bethlehem, Pa., 1919 (Franklin and Charles).—This and the two companion volumes to be mentioned later have been prepared to meet the needs of the two year schedule in elementary physics which has recently been

adopted in some technical schools in which it is no longer possible to base the teaching of physics upon the mathematical courses to the extent that may have been done heretofore. As might be expected, these text books are strongly stamped with the individuality of the author—or authors—even to the appearance of the pages, on which varying degrees of emphasis are marked by seven or eight different fonts of type, *fortississimo* being indicated by 10-point bold face capitals. More important than the superficial appearance of the text is the purpose of the authors toward the teaching of physics. In this volume they express the opinion that the function of physics teachers is to aid in the important and difficult matter of mathematical training and accordingly the calculus methods are introduced from the beginning without presuming previous knowledge of these powerful mathematical methods on the part of the student.

The form of presentation is intended to facilitate class room work. Each topic is introduced with a definite statement, or definition, of the physical meaning of the idea propounded, and so developed as to lead to illustrative numerical problems which are very numerous. Descriptive material has been reduced to a minimum. The figures are well conceived but too sketchy—one might even say scratchy. The chapter headings run through the gamut of Statics, Motion of Translation, Motion of Rotation, Hydrostatics, Hydraulics, Elasticity, and Waves in Elastic Bodies. Three appendices are devoted to Measurements, to Errors, and to Equations of analogous form in Translation, Rotation and Electricity. Controversial subjects are not avoided but as might be anticipated the bull is taken by the horns. To help the student through the slough of gravitational and absolute units the pound mass is denominated the sugar-pound and the pound force is distinguished as the pull-pound or when occurring alone as "pound" in quotation marks. The unit of mass in the gravitational system is always taken as the slug which is the attraction of the earth upon the mass divided by the acceleration of weight.

As far as it is possible for a book to do it the student who has worked through these lessons in mechanics should have been helped to form sound concepts of the physical ideas, to give clear interpretations of mathematical symbols, and to state results free from confusion in the units. F. E. B.

10. *Lessons in Electricity and Magnetism;* by William S. Franklin and Barry MacNutt. Pp. XIV, 254. Bethlehem, Pa., 1919 (Franklin and Charles).—This is the second volume of the series mentioned above and might be called "Things which the beginner in electrical engineering should know." The mode of presentation is peculiar, being developed from the standpoint of electro-mechanics, i. e. instead of starting with the relatively simpler phenomena and proceeding to the more complex, the authors purposely ignore the nature of everything, and postulate the existence of magnets, and of electric currents with the Joule,

the Faraday and the Oersted effects. This method seems to have the purpose not of making the fundamental principles clear so much as to lead by the shortest step from experimental facts to the mathematical statement of relations between certain quantities as measured in the electromagnetic system of units. Thus for example, assuming Joule's law, namely that the rate of generation of heat in a wire is proportional to the square of the current, the resistance R is introduced as a constant of proportionality. As a sequence electromotive force is defined as the rate at which a generator does work per ampere of current. Such a statement reminds one of the definition of force as the space rate of variation of the energy in a field, and though all of these definitions are mathematically correct, few physics teachers would regard them as very helpful to a beginner.

After the first four chapters which treat of electric currents, two are devoted to electrostatics and one to electron theory. Four appendices discuss the Magnetism of Iron, Alternating Currents, Electrical Measurements, and Corresponding Equations.

F. E. B.

11. *Die Stellung der Relativitätstheorie in der geistigen Entwicklung der Menschheit;* by JOSEPH PETZOLDT. Dresden, Sibyllen-Verlag, 1921, 125 pp.—This account of the relativity principle is written in popular form and without the use of mathematical symbols. The author is particularly interested in the philosophic aspects of the theory, and devotes half the book to the historical development of the ideas underlying Einstein's theories. The account of the Michelson-Morley experiment is followed by a discussion of the special theory of relativity. The treatment of Einstein's theory of gravitation, however, seems too brief to give the reader an adequate idea of the significance of this important advance in mathematical physics. L. P.

II. GEOLOGY.

1. *The Earth's Axes and Triangulation;* by J. DE GRAAFF HUNTER. Professional Paper No. 16, Survey of India. Pp. 217; and with six charts and appendix. Dehra Dun, 1918.—This book contains results of a research by J. DE GRAAFF HUNTER, Mathematical Adviser to the Survey of India, which he conducted with a view to developing methods by which the triangulation of India, which was originally computed on the obsolete Everest spheroid, might be referred to what Hunter calls the Helmert spheroid.

The Everest spheroid was adopted for the triangulation of India many years ago and, as in nearly all countries, the officials responsible for the triangulation have hesitated to make a change to a spheroid that is much nearer the truth, but in most cases such a change has been made. In the United States, Bessel's

spheroid had been in use by the Coast and Geodetic Survey for a number of years but this was found to be quite far from the truth after Clarke had carried on his investigations for the determination of the figure of the earth. After that the Coast and Geodetic Survey adopted the Clarke spheroid of 1866 as its reference spheroid and it is believed that this spheroid is so near the truth that, for all scientific and geodetic purposes, it need never be changed, in so far as the triangulation of the United States is concerned. Undoubtedly the Helmert spheroid, which will be adopted by the Trigonometric Survey of India, will meet the needs of India for all time.

Hunter has chapters in his book on the various phases of the change of a triangulation system from one spheroid to another. This includes an interesting statement on the adjustment of triangulation and a chapter on the probable errors of triangulation before and after adjustment. There are included in the publication data for the 108 gravity stations which had been established in India prior to the appearance of this book. The data include the gravity anomalies based on the three generally used methods of reduction, namely, the free air, the Bouguer and the isostatic hypotheses. These data, with regard to gravity stations, are duplicates of the same material appearing in Professional Paper No. 15, of the Trigonometrical Survey of India.

The last chapter of the book contains a discussion of the data relative to deflections of the plumb line and the values of the intensity of gravity at stations established in Turkestan by Russian observers. It is interesting to note on the chart which accompanies the report the relation of the deflections of the vertical to the topography of the area covered by the stations and to their north and south. There is a station close to the southern margin of the valley near the foot of high mountains with a deflection to the southward of 49″.4. To the north of the valley and just to the south of a range of mountains is a station with a deflection of the vertical to the northward of 26″.9. The relative station error between these two stations is 76″.3, while their difference in latitude is only about 65 miles. This is quite a remarkable case and shows the impossibility of having only astronomic observations for the control of surveys and maps. If surveys had been made and maps based on each of these astronomic stations, when the two surveys were joined there would be an overlap, in position, on the resulting maps of about 1½ miles. This is one of the strong arguments in favor of having an area covered by continuous triangulation, as has been done in most of the countries of the world.

The gravity anomalies shown on the Turkestan map have not been reduced by the isostatic method. It is hoped that this may be accomplished at an early date for there has always been great interest attached to the condition of isostasy in Asia, outside of India where much data are available, and here is an opportunity of throwing some light on this important question. W. B.

2. *Investigations of Isostasy in Himalayan and Neighbouring Regions;* by Colonel Sir S. G. BURRARD, 88 pp., 2 plates, appendixes 1 and 2, and map of India. Professional Paper No. 17, Survey of India, Dehra Dun, India, 1918.—This is a welcome report from India on the subject of isostasy. For many years there has been some doubt in the minds of geodesists and geologists in India as to whether isostasy is as nearly perfect in India as it has been found to be in the United States. The present report seems to eliminate all doubt on this matter. The author states that "In the last few monhs, while making experimental calculations I was led to the conclusion that the evidence which we have regarded as unfavourable to the theory of isostasy may be found to prove an unexpected support for it."

The author reviews the opinions of various investigators in the subject of isostasy in India and the results of their work. He pays particular attention to the geodetic observations in the form of values of the intensity of the force of gravity at stations on the Gangetic plain and near it and deflections of the vertical at stations in various parts of India. The gravity values over the Gangetic plain have shown anomalies (difference between the observed and the computed values of gravity) which in nearly all cases are too light. This fact was the principal reason for the conclusion that the Gangetic plain was under compensated, that is that the material in the column under this area has less mass than normal.

Colonel Burrard, in this publication, accepts the opinion of William Bowie, of the U. S. Coast and Geodetic Survey, in regard to the possiblities of an area of recent geologic formation having negative gravity anomalies being in an isostatic condition. He quotes the following from Special Publication No. 40 of the U. S. Coast and Geodetic Survey, entitled "Investigations of Gravity and Isostasy":

"In India there is a broad belt for recent geologic material running approximately east and west at the foot of the Himalaya Mountains. The stations on the recent formation, which no doubt is largely due to the deposition of materials eroded from the mountains, have in general negative anomalies. It is impossible that the addition of materials could make the pressure less than normal on the surface at the depth of compensation. We may therefore conclude that isostatic adjustment probably follows the deposition of materials and that the negative anomaly is probably due to the lighter materials in the upper crust."

Following this quotation from Bowie's publication, Burrard writes:

"In consequence of Bowie's contention that the negative anomalies are evidence of the isostatic compensation of the Gangetic trough, I have lately made a series of calculations to test the correctness of this view. Although in the past I had never been able to perceive any strong geodetic evidence either for or against the isostatic compensation of the trough, I am now of the opinion

that Bowie's contention is probably correct; for reasons which I will subsequently explain, I consider that the evidence available favours the view that the Gangetic deposits are compensated."

Burrard stated that in 1912 he put forward for the consideration of geologists the suggestion that a rift had opened in the crust at the foot of the Himalayas and had formed the Gangetic trough and that it had been filled by abnormally light material. Bowie, on the other hand, stated that the evidence at hand made it possible to account for the gravity anomalies on the Cenozoic formation in the affected area.

Burrard makes a number of computations, the results of which are given in this publication, showing the effect of the excess and deficiency of density that occur in different geologic formations extending below sea level. In his computations he assumes that the light rock deposits of Gangetic troughs are isostatically compensated and he examines whether the observed geodetic results support this assumption or not. After making his computation, Burrard concludes that the geodetic evidence in India supports the view that the Gangetic trough is isostatically compensated. This is a confirmation of the views held by geodesists in America that probably all parts of the earth would be found, after investigation, to be in the same state of isostatic compensation that we have in this country. An appendix to the report gives details in regard to the computation of the depth of the Cenozoic formation at the various gravity stations that would be necessary to account for the anomalies.

The reviewer commends this report to the careful attention of geophysicists and geologists as it is certain that the data furnished by the geodesists in their investigations should be carefully considered in formulating theories as to the crustal movements of the earth. W. B.

3. *Connecticut Geological and Natural History Survey.* Three Bulletins have recently been issued by the State Geological and Natural History Survey. These are: Bulletin **29**, ***The Quaternary Geology of the New Haven Region;*** by FREEMAN WARD. 78 pp., 17 figs., 9 pls., 1920.—On the basis of two seasons' field work, Dr. Ward has prepared a detailed account of the glacial features about New Haven, with especial attention to the source, composition, and manner of deposition of the till, stratified drift, and clays. Evidence is presented of two advances of the ice but no deposits or erosion features indicating an interglacial epoch were found. The glacial history of the New Haven region is similar to that of other parts of the Connecticut coast but unlike that of the central West. Dr. Ward's paper will therefore find a place in comparative studies.

Bulletin **30**, ***Drainage Modifications and Glaciation in the Danbury Region, Connecticut;*** by RUTH SAWYER HARVEY. 59 pp. 5 pls., 10 figs., 1920.—Detailed study of Rocky River, Umpog Brook, and of the reversed Still River, supplemented by an exam-

ination of the structural features and glacial deposits of the Danbury region, has demonstrated that "the lower Housatonic has always maintained its course diagonal to the strike of formations and that differential erosion which reaches its maximum expression in limestone areas is responsible for the impression that the Still River lowland and other valleys west of the Housatonic may once have been occupied by the later stream"—a conclusion opposed to the views of Hobbs (Bull. Geol. Soc. Am., vol. **13**, pp. 17-26, 1901) and of Crosby (Tech. Quart., vol. **13**, p. 120, 1900). The paper by Dr. Harvey has much more than local interest for the physiographic history of the region which includes the Housatonic, the Croton, and the Saugatuck drainage systems involves the interpretation of the topographic features of southern New England.

Bulletin 31. *A Check-List of Connecticut Insects;* by W. E. BRITTON. 397 pp., 1920. The collections of Connecticut insects at the Connecticut Agricultural Experiment Station are the most important in existence. Dr. W. E. Britton has listed these collections in systematic order, following a plan which will make this bulletin an indispensable handbook for professional entomologists and for amateurs interested in the insect life of their home region. The list includes 6,781 species and varieties grouped in 2,946 genera and 333 families. H. E. G.

4. *The Erosional History of the Driftless Area;* by ARTHUR C. TROWBRIDGE. University of Iowa, Studies in Natural History, Vol. **9**, No. 3, pp. 127, figs. 35, 1921.—The contribution of Professor Trowbridge to the knowledge of the unglaciated "island" surrounded by glacial drift and lying at the junction of the States of Illinois, Iowa, Wisconsin, and Minnesota is interesting in method and conclusions. Part I is an analytical discussion of the principles of multiple erosion cycles in which the value of "*sets* of evidences" is emphasized. "The total number of distinguishable cycles is the number of sets of evidences plus one." In Part II, the author applies his principles in writing the physiographic history of the "driftless area" as a whole after detailed study of its parts. The events are: formation at the close of the Paleozoic era of an anticline, the south limb of which was a monoclinorium; making of the Dodgeville plain or peneplain in late Tertiary time; followed by an uplift of about 180 feet; making of the Lancaster peneplain in pre-Kansan Pleistocene; uplift of 600 feet inaugurating a third cycle of erosion which with various episodes continues to the present.

5. *Geological Survey of Western Australia;* A. GIBB MAITLAND, *Government Geologist.*—The Annual Progress Report of the Western Australia Geological Survey for 1919 (48 pp., 1 map) is chiefly a record of reconnaisance in areas from which minerals of economic value have been reported. Summary reports are given for the goldfields on Coolgardie, Yalgoo, Yilgarn, Mont Margaret, Murchison, including the newly

discovered lodes at Wallangie, and on the valuable deposits of residual clays at Bolgart and Clackline. Along the Ponton streamway, Mr. Talbot found bowlders which are believed to have been carried inland by icebergs after the manner of those in the Wilkensen Range (Bulletin 75). Publications for the year include: Bulletin 77. Sources of Industrial Potash in Western Australia: E. S. SIMPSON, I. H. BOAS, and T. BLATCHFORD. Bulletin 82. The Magnesite Deposits of Bulong: F. R. FELDTMANN. Memoir No. 1. The Western Australian Mining Handbook, which is being issued in sections as they are received from the Printing Office. Twenty-one chapters, chiefly description of mineral deposits, have been received. Papers on petrology, prospecting and similar topics are also included in these separate chapters. H. E. G.

6. *Tenth Annual Report of the Director of the Bureau of Mines, for the fiscal year ending June 30, 1920;* FREDERICK G. COTTRELL, Director. Pp. 149 with 3 plates and 2 text figures.—The most important accomplishment of the year has been the completion and dedication of the station and central laboratories of the Bureau at Pittsburgh. This gives it an adequate establishment and headquarters for field and investigative work. The special work carried through is connected with the transition from war to peace conditions. The study of accidents and rescue in mines with the health of the miners is one to which the Bureau has always devoted much attention. During the year, 10,177 miners were trained in first aid and rescue work and assistance was rendered in 27 mine accidents. The activities of the Bureau are so varied and comprehensive that it is only possible to briefly allude to them in the present place.

It is a matter of regret that Dr. Cottrell has been compelled to withdraw as director to take up his duties as chairman of the Division of Chemistry and Chemical Technology of the National Research Council. Dr. Cottrell recommends as his successor H. Foster Bain of California, who during the war served as assistant director.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The System of Animate Nature;* by J. ARTHUR THOMSON. Two vols.; vol. 1, *The Realm of Organisms as it is*, pp. xi, 347; vol. 2, *The Evolution of the Realm of Organisms*, pp. v, 353-687. New York, 1920 (Henry Holt & Co.).—These volumes comprise the Gifford lectures, twenty in number, delivered in the University of St. Andrews in 1915 and 1916. In them the reader will find a broad and sympathetic survey of the entire field of biology, leading from the unfathomed universe to the psychical, ethical, and spiritual nature of man.

Every one of the outstanding generalizations in modern biology is examined in a critical but kindly spirit and brought into harmony with the rest of the system of animate nature. The author

shows how some of the most divergent and apparently irreconcilable theories of vital processes, which have so often led to bitter controversies, may be harmonized without injustice to either side. This attitude is well illustrated in the discussion of the age-long controversy as to whether the living world is ruled by mechanistic or vitalistic forces, for the author's conclusion (p. 133) is that "Our study has led us away from the view that there is only one science of nature, consisting of precise chemico-physical descriptions which have been, or are in process of being, summed up in mechanical or mathematical terms. As it seems to us, there is greater utility and accuracy in frankly recognising successive orders of facts, each with its dominant categories. There is the domain of the inorganic, the physico-chemical order, where mechanism perhaps has it all its own way. There is the realm of organisms, the biological order, where mechanism is checkmated by organism. There is the kingdom of man, the social order, where mechanism is transcended and personality reigns."

The first volume, of ten lectures, treats of the living world as it exists today, including the activities of the living substance, the behavior of animals, the problem of body and mind, the fact of beauty, aesthetic emotion, the issues of life, the tactics of animate nature, adaptiveness and purposiveness. In the second volume the evidence as to the origin and evolution of organisms is presented, with particular reference to man. Five of these lectures deal with variation, evolution, and heredity; the others with the evolution of mind and mind in evolution, phylogeny of man, disharmonies, parasitism, senescence, death, control of life, healing power of nature, the moral and aesthetic development in man and the religious interpretation of nature.

This work will take a leading place among the few books which will give the general reader an intimate, yet sufficiently broad, view of the greatest problems of life and lead him toward a sympathetic understanding of his own relation to the universe.

W. R. C.

2. *Mechanismus und Physiologie der Geschlechtsbestimmung;* VON RICHARD GOLDSCHMIDT. Pp. viii, 251, with 113 figures. Berlin, 1920 (Gebrüder Borntraeger).—The elucidation of the sex-determining mechanism forms one of the most important biological contributions of the present century. Since it has been shown that the differences which distinguish the sexes in man, animals, and plants are normally dependent upon a definite chromosomal complex in the fertilized egg, it is of importance to understand the means by which these sexual characteristics become stamped upon the body.

The author presents experimental evidence to show that in some animals, at least, every fertilized egg possesses both of the alternative sex factors, the predominating activity of one producing the male sex and that of the other the female. These factors are of the nature of enzymes associated with the so-called sex chromosomes. Each of them, male and female determining,

is necessary for a reaction the products of which are the internal secretions (hormones) of sexual differentiation. Goldschmidt's theory of this antagonistic hormone, or endocrine, action is, briefly, that if the potency of the male differentiating hormone exceeds that of the female activator by a certain amount the individual develops the sexual characteristics of the male, and vice versa. An approach to equality of hormone potency results in sterile, intersexual (hermaphroditic) individuals. He shows from experimental data that by mating animals selected for a particular sex potency any desired preponderance of either sex or of exclusively intersexual offspring can thus be obtained.

The book contains an excellent summary of our present knowledge of the sex-determining mechanism and its action in the various groups of animals. W. R. C.

3. *Biology, General and Medical;* by JOSEPH MCFARLAND. Fourth edition, thoroughly revised; 473 pages, with 151 illustrations. Philadelphia and London, 1920 (W. B. Saunders Co.).—The wide usefulness of this college text-book, in which the general principles of both plant and animal biology are correlated with such more distinctly human applications as blood-relationship, infection, immunity, parasitism, inheritance, mutilation, regeneration, grafting and senescence, is shown by the fact that three complete editions have been exhausted in the ten years since the book first appeared. This, fourth, edition has received such revision as was necessary to keep the work in line with recent discoveries. W. R. C.

4. *An Introduction to the Study of Cytology;* by L. DONCASTER. Pp. xiv, 230, with 24 plates and 31 text-figures. Cambridge, 1920 (University Press).—Inasmuch as all biological phenomena are dependent upon the activities of the individual cell, or cells, of which the various organisms are composed, the search for an explanation of any of these phenomena leads directly to the study of the cell. In the past few years the discoveries in this field have been so numerous and so important that the subject of Cytology is now recognized as a special science and as one of the most important branches of biology. The phenomena of heredity, of development, of sex determination, growth, metabolism, reproduction, disease and death can, in many cases, be associated with certain of the wonderful mechanisms of the cells. The determination of the sex of an individual, for example, appears to depend upon the presence or absence in the fertilized egg of a particular one of the many chromosomes. In fact, many of the hereditary characteristics in various groups of organisms have been shown to be the result of the actions of genes situated in more or less definitely localized portions of the individual chromosomes. Only from the study of such cell mechanisms do the observed facts of heredity become intelligible.

The general structure and activities of each of the numerous organs of the cell are described in this book and the function of each of the cell mechanisms are explained as fully as is possible in

a limited space and in the present state of our knowledge. In all cases the bearing of the cytological facts on problems of general biological interest is emphasized. The chapters on natural and artificial parthenogenesis, sex determination, germ-cell determinants, development and heredity show not only how these phenomena are associated with definite cell organs, but also how little is yet known of the many subtle problems involved. The evidence on which the author's conclusions are based is supported by excellent reproductions of the figures of the original investigators. W. R. C.

5. *A Laboratory Manual of Invertebrate Zoology;* by GILMAN A. DREW. Third edition, revised; pp. ix, 229. Philadelphia and London, 1920 (W. B. Saunders Co.).—This well-seasoned work is the outcome of the experience in teaching large classes at the Marine Biological Laboratory for many years. It represents the combined efforts of a number of instructors, for the original manual has been modified from time to time and new topics added until the present edition contains carefully prepared and really usable directions for the laboratory study of nearly a hundred different animals, embracing all the invertebrate phyla.

With so large a number of types for selection, the book can be adapted to the needs of both extensive and briefer courses in any part of the country simply by omitting those forms which are unavailable or thought to be less essential for study. W. R. C.

6. *Considérations sur l'Être Vivant:* première partie, *Résumé Préliminaire de la Constitution de l'Orthobionte;* par CHARLES JANET. Pp. 80, with 1 plate. Beauvais, 1920 (A. Dumontier).—This is a brief summary of the hypotheses relating to the origin of life and the phylogenetic evolution of the primitive living substance into the various groups of plants on the one hand and into the metazoa on the other as indicated by their reproductive processes. The ingenious schematic diagrams make the author's conclusions easy of comprehension. W. R. C.

7. *Collection les Maitres de la Pensée Scientifique;* publiés par les soins de M. SOLOVINE. Paris, 1920 (Gauthier-Villars et Cie). —The object of these publications is to make available in inexpensive form (about 3 francs) the classic works on which the various sciences are founded. The list will include the most famous productions of all times and of all countries, those originally written in other languages to be faithfully translated into French. A brief biograhical notice accompanies each work.

Two of the volumes already issued are reprints of Spallanzani's *Observations et Expériences faites sur les Animalcules des Infusions* from the Geneva edition of 1786. A third includes the Lavoisier's classic *Memoires sur la respiration et la transpiration des Animaux* (1777). W. R. C.

8. *Practical Bacteriology, Blood Work and Animal Parasitology.* Sixth Edition; by E. R. STITT. Pp. xi, 633. Philadelphia, 1920 (P. Blakiston's Son & Co.).—This is a manual for laboratory workers which has proved its usefulness in five pre-

ceding popular editions. There is a modicum of descriptive text to enable the investigator to proceed with intelligent appreciation in the application of the methods described to practical problems of diagnosis. The book is somewhat unique in respect to the systematic manner in which the uses of laboratory clinical diagnosis are presented and also in the large number of data on "normals" which serve as a basis for comparison. Perhaps the book can best be described as a compact, compendious well illustrated vade mecum for those who have occasion to apply either chemical, bacteriological or microscopic technique as diagnostic aids. L. B. M.

9. *Memoirs of the Bernice Pauchi Bishop Museum of Polynesian Ethnology and Natural History.* Volume VI, No. 3. 4to, pp. 359-546.—Fornander collection of Hawaiian antiquities and folklore; by ABRAHAM FORNANDER, with translations by THOMAS G. THRUM.

10. *New Geography, Book I;* by ALEXIS EVERETT FRYE. Pp. viii, 264. Boston, 1920 (Ginn & Co.).—This publication, from the Frye Atwood Geographical Series, is much to be commended for the variety and attractive character of the subject matter as well as for its ample illustrations which include 539 text figures as also a series of geographic and other plates. It differs from the dry publications of an earlier period in style as well as in subject matter and cannot fail to be interesting and instructive to the youthful generation for which it is prepared. Dr. Atwood of Harvard University has lent his assistance and many of the excellent pictures included have already appeared in the National Geographic Magazine. There is also a supplement giving the population of the principal cities, relief maps and other matters of interest.

11. *Memoirs of the Queenland Museum,* HEBER A. LONGMAN, Director, Volume 7, Part I, Brisbane.—This issue contains papers on several natural history subjects. One of these is a continuation of the edible Fishes of Queensland by J. DOUGLAS OGILBY. Two papers are devoted to Queensland flies, one by T. H. JOHNSTON and M. J. BANCROFT; another by C. P. ALEXANDER. The occurrence of the little Penquin is noted by the Director, H. A. LONGMAN.

12, *Transactions and Proceedings of the New Zealand Institute, Wellington, N. Z.* Volume 52 (new series).—This embraces 544 pages with a large number of plates and text figures. The field covered includes anthropology, botany, chemistry, geology, and zoology, and many of the papers merit an individual notice which is here impossible.

13. *The National Academy of Sciences.*—The Annual Meeting of the National Academy of Sciences will be held at the United States National Museum, Natural History Building, April 25 to 27, 1921. Several features of unusual interest are promised. The Prince of Monaco, who is to receive the Agassiz Medal, will give an address on Monday evening, April 25, on his long continued and highly valued researches in oceanography. ...ther occasion Dr. W. S. Adams, of Pasadena, will speak of

his many years of investigation whereby for the first time the spectrum classification, distances, absolute magnitudes, velocities, and directions of motion in space of nearly 2,000 stars are fully known, so that a new far-reaching view of the arrangement of the stellar system appears.

A large attendance is anticipated and the Home Secretary, Dr. C. G. Abbot, has already called for a list of papers, from those of 10 minutes in length to others embracing 15 to 30 minutes.

14. *Observatory Publications.*—Recent acquisitions include the following:

The Annual Report of the Naval Observatory for the fiscal year 1920.—This forms appendix No. II to the annual report of the Chief of the Bureau of Navigation.

Washburn Observatory of the University of Wisconsin, volume **13**, part 1; by Albert S. Flint, Astronomer.—This important work contains meridian observations for stellar parallax, from 1898 to 1905. These were conducted by the method of meridian transits similar to those of volume **11** of the observatory, with some minor changes in conditions. Twelve students were employed in the computations, chiefly graduates and undergraduates. The list of stars observed extends from —35 degrees in declination to the Pole.

Leander McCormick Observatory of the University of Virginia, volume III—Parallaxes of 260 Stars, by S. A. Mitchell.

Publications of the Yerkes Observatory, volume IV, part III.—Parallaxes of fifty-two stars; by Georges Van Biesbroeck and Mrs. Hannah Steele Pettit.

Contributions from the Princeton University Observatory, No. 5.—Photometric researches: the eclipsing variable, U Cephei; by Raymond Smith Dugan.

15. *A Laboratory Manual of Anthropometry;* by Harris H. Wilder, professor of zoölogy at Smith College, Northampton, Mass. Pp. 200, 43 illustrations. Philadelphia, 1920 (P. Blakiston's Sons & Co.).—In order that the records of each observer may be readily made use of by every other observer, it is imperative that series of measures be uniform and be taken in uniform ways. The matter of unification was first placed upon an international basis by the International Congress of Anthropologists held at Monaco in 1906. The unification process was carried still further at the Geneva Congress in 1912. There remain for consideration at some future Congress the general skeletal measures, exclusive of the cranium and lower jaw.

The work of the special International Commissions of the two Congresses rightly forms the basis of Wilder's Laboratory Manual. However his statement on page vi of the preface, that the periodicals in which the reports of the labors of the two Commissions "appeared were exclusively European" is incorrect; for report from the reviewer's pen of the work accomplished at Geneva appeared both in the American Anthropologist and in Science for the year 1912.

To the measures accepted by international agreement, the author adds a convenient and useful list of general skeletal measures, as well as angles and indices. No mention is made of the spheno-maxillary angle, which might well find a place even in an abridged manual. His enumeration of instruments and description of the manner in which they are employed are done with a thorough knowledge of the difficulties which beset the beginner. The pages devoted to simple biometric methods were written for the benefit of the student, whose chief interest is in morphological relations, and whose mathematical ability and training are not sufficient to enable him to follow abstruse biometric methods.

To the laboratory student of the subject, Wilder's Manual is recommended for its lucidity and conciseness, as well as for the author's ability to transmit a maximum amount of his own pervading enthusiasm for the subject by means of the printed page. For good measure, two instructive appendices are added: A, Measures of Skulls of 93 Indians from Southern New England; B, Bodily Measures of 100 Female College Students.

Yale University. GEORGE GRANT MACCURDY.

OBITUARY.

DR. WILLIAM T. SEDGWICK, professor of biology and public health at the Massachusetts Institute of Technology, authority on biology and sanitation, and for a time president of the American Health Association, died suddenly on January 26. He was born in West Hartford, Conn., in 1855, was graduated from Sheffield Scientific School in 1877, and received the degree of Ph.D. from Johns Hopkins in 1881. Among his many activities he was curator of the Lowell Institute, Boston, 1897; he was also a member of the advisory board Hygienic Laboratory, United States Public Health Service, 1902, and at one time president of the Boston Civil Service Reform Association.

He was a man of charming personality and the value of his services to this country from east to west, particularly in biology and sanitation, can hardly be overestimated.

SIR LAZARUS FLETCHER, the distinguished English mineralogist, died in January in his sixty-seventh year. In addition to his many and important contributions to his department of science he was the keeper of the mineral department of the British Museum for some forty years; in this connection he had the responsibility for the removal and installation of the collections from their early home at Bloomsbury to the new Museum of Natural History in South Kensington.

DR. LINCOLN WARE RIDDLE, assistant professor of cryptogamic botany and associate curator of the Farlow Herbarium, died at Cambridge on January 16 in his forty-first year.

DR. ALEXANDER MUIRHEAD, the British physicist, died on December 13 at the age of seventy-two years.

FRÉDÉRIC HOUSSAY, professor of zoology at the Sorbonne since 1904, and dean in 1919, died recently in Paris.

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

ART. XVIII.—*Determinate Orbital Stability: its Mechanism and some of its Functions in Celestial Mechanics*; by FRANK BURSLEY TAYLOR.

CONTENTS.

Introduction.

The subject to be considered in this paper is the stability of the Moon's revolution around the Earth, with special reference to the *quality* of that stability, whether it be *determinate* or *indeterminate* in a sense defined below. I have not as yet seen any writing in which the quality of the stability of the Moon's revolution is considered from the point of view here presented. Present and recent textbooks and treatises discuss the motion of the Moon and the perturbing action of the Sun's attraction, but they seldom mention stability as such, and do not discuss its quality.

The Three Kinds of Equilibrium.

Before beginning the discussion of the quality of the Moon's stability, it is necessary to take note of certain theoretical considerations which have an important bearing on this subject.

The general definition of the word "equilibrium" is given as "equipoise; the state of being equally balanced; a situation of a body in which the forces acting on it

balance one another." Then continuing by way of elaboration and further definition, three kinds of equilibrium are defined as follows:

"When a body, being slightly moved out of its position, always tends to return to its position, the latter is said to be one of *stable equilibrium;* when a body, on the contrary, once moved, however slightly, from the position of equilibrium, tends to depart from it more and more, like a needle balanced on its point, its position is said to be one of *unstable equilibrium;* and when a body, being moved more or less from its position of equilibrium, will rest in any of the positions in which it is placed, and is indifferent to any particular position, its equilibrium is said to be *neutral or indifferent.*"

A needle balanced on its point is a typical illustration of an unstable equilibrium. A billiard ball of homogeneous composition and density, resting on the smooth surface of a billiard table, is in equilibrium. If it be moved to any other place on the table it will rest there in its new position just as well as in its first position, and it has no tendency to return to its first position. This is a typical illustration of neutral or indifferent equilibrium. A weight freely suspended by a cord from a fixed point hangs toward the center of the Earth, and is in equilibrium. If it be pushed aside in any direction it will oscillate for a time, but will always return at last to its original position as the only place where it can find equilibrium. Thus, every force or impulse which disturbs the suspended weight from its original position brings into action another force which causes it to return to that position. This device is called a pendulum, and is a typical illustration of stable equilibrium.

The distinctions between these three kinds or qualities of equilibrium are useful in connection with the present paper, because, theoretically, they may be taken to represent corresponding types of stability in orbital revolution, and hence furnish a convenient basis for a determination of the quality of the stability of the Moon's revolution around the Earth.

[1] From the *Century Dictionary.* This definition was chosen rather than one from a textbook of physics or dynamics mainly because it suited the present purpose better than any found in such sources. In his "Physics," (advanced course), 1892, page 79, Prof. G. F. Barker defines Statics as "that branch of Dynamics which investigates the action of force in maintaining bodies in equilibrium." . . . "Matter in motion is in equilibrium when its acceleration is zero." Referring to the equilibrium of floating bodies on pages 160 and 161, Barker defines the three kinds and gives them the same meanings as are given above.

Equilibrium and Orbital Stability.

In the *Century Dictionary,* the word "stability" is defined as "The state or property of being stable or firm; strength to stand and resist overthrow or change; stableness; firmness; as, the stability of a building, of a government, or of a system."

Stability is not synonymous with equilibrium, and yet, theoretically, there are three kinds or qualities of stability, as applied to the Moon's revolution around the Earth, which correspond closely with the three kinds of equilibrium defined above. The Moon's revolution is commonly regarded as stable, because the forces which act upon the Moon appear to be, on the whole, balanced against each other. This is a fair primary assumption and seems forced upon us by the relatively long record of observations of the Moon, covering the entire period of human history. It is hardly possibly to determine from a study of the Moon's observed motion alone, what kind of equilibrium characterizes its present revolution. It is therefore necessary to enquire more narrowly into the theoretical relations of the forces involved, before the kind of equilibrium can be determined.

The quality of equilibrium is revealed to the best advantage, it seems to me, by considering the action of the forces in an imaginary case in which the Moon is supposed to revolve in some other orbit than its present one, either at a less or a greater distance from the Earth, and comparing the action of the forces in this case with their action in its present orbit. By this method we may be able to determine what kind of equilibrium characterizes the Moon's present revolution, and to what quality of stability this kind of equilibrium corresponds.

If, for example, the relation of the forces affecting its revolution is such that the least departure of the Moon from its present orbit brings into action a force which causes it to depart still more widely from its orbit and, finally, to leave it never to return, then the Moon's equilibrium is unstable. The corresponding relation described in simple terms of stability would be "unstable stability"; but these words form a contradiction in terms. The relation in this case is better defined as *instability.* Stability of this kind, however, is manifestly impossible as the basic principle of stable revolution. For this discussion, therefore, instability has no value, except as a

theoretical concept, and may therefore be dismissed without further remark.

With instability eliminated, only two kinds of equilibrium remain which may be used in determining the quality of the Moon's stability. If the relation of the forces affecting the Moon's revolution is such that a departure of the Moon from its present orbit, either to an orbit situated nearer to the Earth or to one farther out, brings into action no force which tends to make it unstable in its new position, so that it is a matter of indifference at what distance the Moon's orbit is from the Earth, its revolution being just as stable at one distance as at another, then the Moon's equilibrium is neutral or indifferent. The corresponding type of stability might, of course, be called neutral or indifferent stability; but a better term is available. From the fact that the action of the forces in this case sets no particular place or distance from the Earth for stable revolution on the part of the Moon, but, within certain relatively wide limits, allows revolution to be equally stable at any distance, this kind of stability may be appropriately called *indeterminate* stability.

If, on the other hand, the relation of the forces affecting the Moon's revolution is such that every departure of the Moon from its present orbit, either toward a smaller orbit nearer to the Earth or toward one larger and farther out, brings into action a force which tends to drive the Moon back to its present orbit, as the only place in which the forces balance each other and produce equilibrium, then the Moon's equilibrium is stable. The corresponding expression in simple terms of stability would be "stable stability;" but this expression is objectionable, because it is plainly tautological. In fact, the adjective "stable" can not be happily applied to the term stability, either in a positive or a negative sense. From the fact that, under given conditions, the forces in this case fix one particular place for stable revolution on the part of the Moon, at a distance from the Earth which is definitely determinate and calculable, this kind of stability may be appropriately called *determinate* stability.

If the Moon's stability in its present orbit is determinate in this sense, then so long as the present fundamental conditions of its revolution remain unchanged, it can not have stability in any other orbit, either nearer to or

farther from the Earth. The essential conditions are: The mass of the Earth, the mass of the Sun, and the distance of the Earth from the Sun. With these elements given, the place of the Moon's stable orbit of revolution is at a definite, determinate distance from the Earth. In terms of determinate stability, this means that if the Moon were started toward the tangent at a distance, say, of 60,000 miles from the Earth and with velocity appropriate to circular revolution under the Earth's power of attraction at that distance, it would not be stable in that orbit, but would be gradually driven out to its present orbit at 240,000 miles, where its revolution would become stable. On the other hand, if the Moon were started toward the tangent at a distance, say, of 480,000 miles, with velocity appropriate to circular revolution under the Earth's power of attraction at that distance, it would not be stable in that orbit, but would be gradually driven in to its present orbit at 240,000 miles, as the only possible orbit for stable revolution under the existing values of the fundamental conditions.

In contrast with this quality of stability, that quality which corresponds to a neutral or indifferent equilibrium has been characterized above as indeterminate. In this case the relation of the forces which make for equilibrium is such that, under present conditions, the Moon's revolution would, within relatively wide limits, be stable in any orbit around the Earth in which it happened to be started. For example, it would be just as stable in an orbit at 60,000 miles from the Earth or in one at 480,000 miles, as in its present orbit at 240,000 miles.

From these considerations we see that stability in the abstract is open to the same theoretical distinctions of kind or quality as those which apply to the abstract idea of equilibrium; and further, that the concepts of the three kinds of equilibrium upon which the three abstract qualities of stability are based are general principles and are so simple and elemental that their validity will hardly be questioned. It seems certain, therefore, that these abstract distinctions are applicable to the concrete case of the Moon's stability in its revolution around the Earth. Hence, no matter what the particular mechanism of the Moon's stability may be, it must fall under one or the other of the two possible kinds of stability defined above—instability, corresponding to an unstable equilibrium,

being eliminated. So strong are the grounds for this conclusion that it may be affirmed positively that no third alternative exists; the Moon's stability must be either *determinate* or *indeterminate.*

The Mechanism of Determinate Orbital Stability.

In discussing the Moon's motion and stability, it is desirable for the present purpose to do it in the simplest possible way. Let it be supposed that both the Earth and the Moon revolve in circular orbits around their primaries, and that the plane of the Moon's geocentric orbit is coincident with the ecliptic. Then, while the Moon revolves in a circle around the Earth, the Earth itself revolves in a circle around the Sun, so that the Moon's true path around the Sun is an epicycle. Plotted in a diagram, this path is a wavy line passing alternately inside and outside of the Earth's orbit, and crossing it twice in each period. The assumption of these simplified conditions will in no way invalidate the conclusions reached.

Upon careful examination, it was found that the Newtonian or current analysis of the Moon's motion does not show the Moon's orbital stability to be determinate; in fact, it shows stability to be *indeterminate.* It was necessary, therefore, to devise some other method of analysis. The method employed here has grown naturally out of the study of determinate stability and the elements which enter into it, and, in general outline, it is believed to be the best if not the only method by which the mechanism can be correctly analyzed. This method proceeds by a direct analysis of the forces of the epicycle, *i. e.*, by a direct study of the forces which affect the Moon as it moves along its epicyclic path around the Sun, and avoids the customary assumptions of the Newtonian analysis by which the heliocentric motion of the Earth-Moon system is transferred to the Sun regarded as a distant satellite, and by which the motions of the Moon and the Sun are referred to the Earth as to a relative center. (See "Outlines of Astronomy." By Sir John Herschel. Edition of 1876, page 415, section (610).)

For every possible circular orbit around the Earth, there is, theoretically, a corresponding epicycle, and since in each case the geocentric circle is simply the epicycle with the heliocentric motion eliminated, the values for

geocentric velocity and radius in the two forms are always exactly the same. Supposing the Moon to revolve around the Earth in the direct order, or from west to east, the several forces affecting it are most simply related at the point of opposition, being there compounded, and hence at their maximum values, the only important exception being the Sun's angular pull when the Moon is in quadratures. This force, in effect, augmenting the Earth's attraction for the Moon, is at its maximum in quadratures and disappears in syzygies. I have therefore confined discussion mainly to the forces as they appear in opposition.

On account of differences of distance, the Moon at the point of opposition in every possible epicycle is acted upon by different values of attraction both on the part of the Earth and the Sun. On this account the Moon has in every separate epicycle a different velocity and curvature, not only with respect to the Earth, but also with respect to the Sun. From this fact the so-called centrifugal force which depends upon velocity and curvature (abstract formula $\frac{mv^2}{r}$) has a different value at the point of opposition in every separate epicycle, not only with respect to the Earth, but with respect to the Sun also. With changes of the Moon's orbital distance from the Earth, the attractions of the Earth and the Sun *vary at different rates,* and in order to maintain stable revolution, the Moon must obey the forces of both bodies. Such a relation suggests the possibility of adjustment like that required theoretically for determinate stability.

Suppose the Moon were started to revolve around the Earth in an orbit at a distance, say, of 60,000 miles, its motion being toward the tangent and at the precise velocity appropriate to circular revolution around the Earth under its power of attraction at that distance. Under the law of velocities in circular orbits (velocities in circular orbits vary inversely as the square root of the distances), the Moon's velocity around the Earth at that distance would be twice what it is now, or about one mile per second, and its periodic time or month would be one-eighth of the present month. The epicyclic path with reference to the Sun would, of course, be very different from the Moon's present epicycle. The Moon's velocity with respect to the Sun would be about 19½ miles per

second in opposition, its present velocity at that point being 19 miles per second, and the curvature of the Moon's path with respect to the Sun would also be sharper than now in opposition. The Sun's attraction would also be slightly stronger on account of a reduction of distance amounting to about 1/500th.

Conversely, if the Moon were started in perfectly adjusted revolution in an orbit, say, 480,000 miles from the Earth its velocity of revolution around the Earth would be slightly less, and its periodic time longer, producing, of course, a very different epicycle from the present one, its curves being longer and more gentle. With respect to the Sun, the Moon's velocity would be slightly less than now in opposition, and the curvature of its path less sharp. The Sun's attraction would also be slightly weaker on account of the greater distance. The masses of the Sun and the Earth and the Earth's distance from the Sun remaining the same as now, would the Moon's revolution be stable in either of these orbits?

If stability is indeterminate the Moon's revolution would be as stable in one of these orbits as in another, for the distance of the orbit from the Earth would be a matter of indifference. But if stability is determinate, then the Moon's revolution would not be stable in either the smaller or the larger of these orbits, or, in fact, in any orbit other than the one in which it now revolves at a distance of 240,000 miles.

It seems clear that in the case of a body having free motion in space, like the Moon, stability can be made determinate in the sense defined above only through the action of opposing forces related to each other in such a way that every departure of the Moon from its present orbit immediately brings into action a force that tends to drive it gradually back to that orbit, as the only place in which the opposing forces are in equilibrium. This kind of action is characteristic of a *differential* relation of forces. The principle of differential action of forces is common in many branches of mechanics, in electrical science, etc., and there is no apparent reason why it may not play an important part in celestial mechanics. We may therefore assume, tentatively, that the place of the Moon's stable orbit is controlled by an automatic differential mechanism—a natural one; and the only forces available with which to produce a differential adjustment

are gravity and inertia, the centripetal and the so-called centrifugal forces. Supposing stability to be determinate, it is fair to assume, experimentally, that the Moon's present distance from the Earth is maintained at 240,000 miles by a differential adjustment in which the centripetal and centrifugal forces are, on the whole, exactly balanced against each other.

At the point of opposition in the epicycle, the Earth and the Sun pull together and pull the Moon toward the Sun, so that the combined centripetal forces are at the moment at their maximum value, and are, in effect, *heliocentric forces.* The velocity and curvature of the Moon's motion with reference to the Sun are also at their greatest value at this same moment, and the inertia with which the Moon resists the deflecting force of the combined attractions naturally produces a like increase of centrifugal force. The combined centrifugal forces are, therefore, at their maximum value at the same moment, and since they are merely responsive forces brought into existence by the action of the heliocentric centripetal forces, their action must vary in the same order and concurrently with those forces. At 240,000 miles the forces are, on the whole, exactly balanced against each other and stability is assured. In an orbit at 60,000 miles, both the centripetal and centrifugal forces would be largely increased. But would they be increased by exactly the same amounts, and would they show the same balanced relation that they show in the present stable orbit at 240,000 miles? One can imagine a case in which the Moon might be made to contract its orbit *gradually* from its present place to an orbit at 60,000 miles. We should then see the two forces just mentioned *increasing gradually* from their present values to the greater values they would have in the smaller orbit. Would the two forces increase at *precisely the same rate,* or would they increase at *slightly different rates?* This, it seems to me, is the vital point in the problem of stability. Up to the present time it seems to have been assumed by every one that these forces must always vary at precisely the same rate; but is there any inherent reason why this should be so? And if they do not increase at the same rate which one increases at the higher rate?

If the two forces in the differential mechanism increased at precisely the same rate there would be no reason why the Moon should be unstable in the smaller

orbit. It would, in fact, be just as stable at 60,000 miles as at 240,000 miles. If the centripetal element increased at a slightly higher rate than the centrifugal, then the Moon in the smaller orbit would be unstable, for it would constantly tend to draw in nearer and nearer to the Earth, and would have no tendency to return to its present orbit. Clearly, this would be unstable equilibrium, corresponding to unstable revolution or instability. But if, on the other hand, the centrifugal force increased at a slightly higher rate than the centripetal the Moon would tend to expand its orbit from its place at 60,000 miles, and would gradually move out to its present orbit, where its revolution would be stable. This would be stable equilibrium, corresponding to determinate stability, and would be attained and maintained by a true differential adjustment of centripetal and centrifugal forces.

The same goal is reached if we consider the Moon's revolution in a larger orbit than the present. In this case both forces would *decrease* as the Moon, under our experimental hypothesis, gradually expanded its orbit to a more distant place. Here again, if both forces decreased at precisely the same rate there would be no cause for instability, because the Moon would be as stable at 480,000 miles as in its present orbit. If the centripetal force decreased at the higher rate the Moon would go on expanding its orbit indefinitely, and would never return to its present orbit—plainly, instability. But if the centrifugal force decreased at the higher rate the centripetal force would become dominant, and would cause the Moon to contract its orbit back to its present place. Thus, from both directions—from a larger orbit as well as from a smaller one—the differential action of the forces would drive the Moon back to its present place, as the only place where its revolution would be stable under the present values of the fundamental conditions. These theoretical considerations show that a differential mechanism, like that here described, will make stability determinate, provided that in changes of the distance of the Moon's orbit from the Earth, the centrifugal factor varies at a slightly higher rate then the centripetal.

We have now reached a point from which we can see more clearly the basic conditions of determinate stability. These conditions grow out of the relation of the Moon to the attractions of the Sun and the Earth, and depend

upon the fact that the powers of attraction of the two larger bodies vary at different rates with changes in the distance of the Moon's orbit from the Earth. This relation makes possible the differential adjustment between the centripetal and centrifugal forces which gives stability its determinate character.

The Moon obeys the attracting powers of both the Sun and the Earth coincidently or in one and the same motion, and if stability is to be maintained the Moon must not fall out of adjustment in the least degree with the attraction of either one of the other bodies, except to such an extent and in such a manner, that the maladjustment to that body will be perfectly compensated by the attraction of the other body. In any orbit in which this compensation fails, stability cannot exist.

The Sun has a certain power over the Moon, depending upon the Moon's distance. The changes in this power with changes in the Moon's distance may, perhaps, be more easily percieved by supposing the Earth to be absent, the Moon revolving alone as a planet. Let the Moon be supposed to revolve around the Sun in a circular orbit concentric with the Earth's orbit, but at a distance 240,000 miles farther out. The Sun now causes the Earth to fall from the tangent 0.119ths of an inch in one second of time, and its power over the Moon 240,000 miles farther out is 1/90th less. Hence, the Moon would fall a slightly smaller distance from the tangent in one second, and its velocity and the curvature of its motion would be slightly less than those of the Earth in its orbit. In other concentric circular orbits nearer to the Earth's orbit, the velocity and curvature of the Moon's motion would be slightly greater, but in all of them it would be less than those of the Earth, because the Moon's distance from the Sun in opposition would always be somewhat greater than that of the Earth. Thus, the Sun's increase of power over the Moon, as the Moon revolved in orbits nearer to the Earth, would be gradual and relatively small. The amount of increase is absolutely fixed by the law of gravitation, and we see, therefore, that the Sun has no reserve power by which it can increase its hold on the Moon in order to compensate a maladjustment to the Earth.

On the other hand, the distance of the Moon from the Earth being so much less than that of the Earth from the Sun, the Earth's power over the Moon increases at a rela-

tively high rate as the Moon revolves in orbits nearer and nearer to the Earth. At 240,000 miles the Earth pulls the Moon from the tangent 0.0535ths of an inch in one second of time. In an orbit 60,000 miles from the Earth, the Earth's power over the Moon is sixteen times as great, and the Moon would fall from the tangent 0.856ths of an inch in one second. In an orbit 15,000 miles from the Earth (1/16th of the Moon's present distance), the Earth's power over the Moon would be 256 times as great as it is now, and the Moon would fall from the tangent 13.696ths inches in one second of time; and in orbits nearer to the Earth these numbers would be still greater. Thus, as the Moon moves in orbits nearer to the Earth, the Earth's power over the Moon increases at a much higher rate than the Sun's power. Stability, and the possible limitations of stability under such conditions, seem to me to present a real problem.

The Earth's velocity of motion around the Sun is now about 18½ miles per second, and the Moon's velocity around the Earth is slightly more than half a mile per second. Thus, at the point of opposition in the epicycle, the Moon's velocity with reference to the Sun is now about 19 miles per second, and stability is maintained with this excess of heliocentric velocity as one of its conditions. In an orbit at 60,000 miles, the Moon's heliocentric velocity in opposition would be about 19½ miles per second, and in an orbit at 15,000 miles, it would be about 21½ miles per second. Along with this increase of velocity, there would also be a relatively rapid increase of heliocentric curvature in that part of the epicycle, due to the greater fall in one second of time from the tangent. The amount of increase in the Earth's power over the Moon, as the Moon revolves around the Earth in smaller and smaller orbits, is absolutely fixed by the law of gravitation, and we see, therefore that the Earth has no reserve power by which it can increase its hold upon the Moon in order to compensate a maladjustment to the Sun. In an orbit of 60,000 miles radius, the Moon in obeying the Earth's attraction would move too fast in opposition for the Sun to do its part in holding the Moon to the curve of the epicycle. But if the Sun fails the Earth must also let go. This means a gradual expansion of the geocentric orbit and of the epicycle, and this expansion would continue until the Moon reached its present place, where the forces would come to a differential balance.

Having the higher rate of increase of power over the Moon, the Earth's influence is the chief variable. The Sun's power forms a relatively even and less variable background upon which the Earth compels the Moon to revolve in epicycles of greater or smaller radius, as temporary influences or hypothetical conditions may require, until, at a certain determinate orbital distance a differential adjustment is attained and stability is established. In a geometrical diagram, the relation of the centripetal and centrifugal forces may be shown by two gently curved lines. At the point marking the Moon's present distance from the Earth, the two lines would intersect, on account of the different rates of variation of the forees they represent, and this point would mark the place of the differential balance of forces and the distance of the determinate orbit of stability from the Earth. Nearer to the Earth, and also farther away, the lines would gradually diverge and would indicate conditions of instability, with the centrifugal forces slightly the stronger in orbits nearer to the Earth, and the centripetal forces slightly the stronger in orbits farther out.

This, as I see it, is the mechanism of determinate stability. Whether this principle is true or not depends mainly, in the first instance, upon what it explains or seems to explain—how many important things, how wide a range of phenomena—and later, upon what results are attained by mathematical treatment. Being unable to offer mathematical proofs, my method has been to proceed by assumption. Taking the principle of determinate stability as here set out to be true, I proceeded to explore the fertile fields of astronomy, more particularly that of the Planetary system. It is a well established principle in modern science that a hypothesis which explains things in a reasonable and plausible way is worthy of at least temporary consideration, and that one which explains not only the things which it was intended to explain, but also many other things which were not contemplated at the time it was formed, carries with it a strong presumption that it is true or comes sufficiently near to the truth to warrant further study and investigation. For first proofs, which, it seems to me, ought to be regarded as justifying further research, I can only call attention to the many remarkable correspondences of phenomena with expectation based on this hypothesis, and to the beauty, harmony, and wide unity of the pheno-

mena of the Planetary system, including its structure and its growth, when interpreted in the light of this principle.

Some Functions of determinate Orbital Stability in Celestial Mechanics.

1. The place of the determinate orbit of stability now occupied by the Moon depends upon the masses of the Sun and the Earth, and the distance of the Earth from the Sun. A change in the value of one or more of these basic conditions would necessarily change the value of some of the factors entering into determinate stability, and would change accordingly the distance of the determinate orbit from the Earth. For example, an increase in the Earth's mass, other conditions remaining the same, would set the determinate orbit farther out from the Earth, while a decrease would set it in nearer. Changes in the Earth's distance from the Sun would produce similar effects upon the place of the determinate orbit. Thus, if the Earth, with its present mass, were revolving in the present orbit of Mars the place of the determinate orbit would be much nearer to the Earth. Mars is both smaller in mass and farther out from the Sun than the Earth, and as a consequence its two moons are remarkable for their nearness to their primary. This phenomenon has been something of a puzzle to astronomers and mathematicians ever since these moons were discovered, but it needs no other explanation. Phobos, the inner of the two moons, is now in the orbit of determinate stability for Mars. A change in the Sun's mass, other conditions remaining the same, would have similar effects, but this is not important for our present purpose.

2. Mathematicians have found that each planet is surrounded by a belt or zone of space in which the attraction of the planet is dominant over that of the Sun. This space is called the planet's *sphere of control*. A theoretical outer limit to this sphere has been defined, but an inner limit has not been suggested. However, since the Moon revolves in the theoretical determinate orbit for a satellite of the Earth, and would not be stable in any other orbit nearer to the Earth, it is plain that the Moon's present orbit marks the inner limit of stable revolution. In an earlier publication,[2] I have called the space between

[2] The Planetary System. Published privately in 1903. Chapter X; The satellite zone; pages 131-141.

these limits the *satellite zone*. Within this zone a planet may have satellites in stable revolution, but they cannot be stable either inside of its inner limit or outside of its outer limit. This fixing of an inner limit to the satellite zone is the first and one of the most important applications of the principle of determinate stability to the phenomena of the Planetary system. It applies, of course, not to the Earth-Moon system alone, but to all of the planets. In the case of those planets which have satellites, the inner satellite in each system occupies the determinate orbit of stability for that system, and marks the inner limit of its satellite zone. Having no satellites, the determinate orbits of Venus and Mercury are not thus marked, but their places can be calculated. In the cases of Uranus and Neptune, it seems certain that their inner satellites have not yet been discovered.

3. It is a corollary to the principle of determinate stability that the original action of the forces which make for stability tends to reduce high eccentricities and inclinations of plane to a lower order, and finally to a near-circular state in a plane near to the ecliptic. For example, the determinate orbit of stability for the Earth being what it now is (corresponding to the Moon's present mean circular orbit around the Earth), we may illustrate by supposing the eccentricity of the Moon's orbit to be much greater than it really is, perigee being considerably farther inside, and apogee much farther outside of the present mean circular orbit than they now are. When the Moon is outside of the determinate orbit, the forces which make stability determinate tend to drive it gradually in, and when it is inside the same forces tend to drive it gradually out; but the forces act with more power in the latter situation than in the former. Thus, eccentric orbits tend to be reduced in both parts, with the result that any very eccentric or much inclined orbit is gradually wound down to one of less eccentricity and less inclination, and this change is the direct result of the action of the primary forces which enter into the mechanism of determinate stability.

4. It is a further corollary of the principle of determinate stability that planets may acquire satellites by the direct capture and retention of wandering planetoid bodies. If the Earth were now without a satellite it would carry its satellite zone just the same, spread like

an imaginary net ready to catch anything that came along, and if some wandering planetoid (cometary nucleus), revolving around the Sun in a more eccentric orbit than that of the Earth, and with its aphelion close to the Earth's orbit, were overtaken by the Earth it might pass close enough to be strongly perturbed, and in so doing, it might enter the satellite zone and be unable to escape, being retained thereafter as a permanent satellite. This, on the present hypothesis, is the method of origin of all satellites.[3]

5. But in order to understand how systems holding more than one satellite may grow, it is necessary to consider another corollary. In a case like the Earth-Moon system in which the planet already has one established and well-regulated satellite, a second satellite may be acquired and installed (if the satellite zone is wide enough), in precisely the same manner as the first one, except that during the process, the previously established or first satellite is gradually driven out to a more distant orbit, where, at the end of the process, if finds stable revolution as the second satellite of the system. The winding down of the orbit of the newly captured member, and its installation in the determinate orbit as the nearest satellite takes place concurrently with the expansion of the orbit of the first satellite and its installation in a larger orbit as the second satellite.

It is practically impossible for the second satellite to be inducted directly into stable revolution in an orbit outside of the previously established member, for this would require at the outset a very small degree of eccentricity and of inclination of plane, in combination with just the right velocity and direction of motion—adjustments

[3] A capture hypothesis in some respects resembling that set forth here and in my earlier writings is put forth with considerable elaborateness and with mathematical treatment by T. J. J. See in his "Researches on the Evolution of the Stellar Systems;" part II, "The Capture Theory," 1910. See's hypothesis differs fundamentally from mine in the fact that he makes no mention nor any use of the principle of determinate orbital stability. From my point of view, the winding down of the orbit of a planetoid during capture and installation is accomplished through the forces which make stability determinate, as stated above. See appears to rely wholly upon a resisting medium in space for the winding down of orbits. For this reason, he finds no determinate place for the orbit of the new satellite, nor any law of growth for satellite systems. An inner limit to the satellite zone can hardly be established by a resisting medium alone, nor can it furnish a principle of adjustment for the second and later satellies of a growing system. In See's hypothesis, the later satellites are simply "taken on," apparently in random fashion. No details of the process are given.

much too nice to be the normal result of the capture of wandering planetoids which must necessarily enter the system in a random fashion, and almost always with relatively high eccentricity and inclination. Instead, the newly captured planetoid would normally revolve at first in a relatively eccentric and highly inclined orbit not systematically adjusted to the pre-existing system, generally having perigee inside, and apogee far outside of the determinate orbit. Its orbit would resemble that of a comet more nearly than that of a planet or an established satellite.

6. With the principle of determinate stability in hand, the mechanism of the expansion of the orbit of the previously established satellite falls smoothly into place as an indispensable part of the larger mechanism. We have seen that if the Earth's mass were greater than it is the determinate orbit would be farther out from the Earth than the Moon's present orbit. Hence, any increase of a planet's mass, *or any change that produces an equivalent effect, even if only temporary in its action,* tends to drive the previously established inner satellite out to a greater distance from its primary. This means that if any planetoid body, say with mass like that of an average satellite, should pass between the Earth and the Moon it would have the effect of temporarily increasing the mass of the Earth, and under the action of the forces which enter into determinate stability, would give the Moon a slight impulse to move out to a greater distance from the Earth. Even if each impulse be very minute and its effect only temporary, yet each such encounter would repeat the impulse, and thousands of successive impulses would cause the Moon to gradually expand its orbit; and this would continue until the Moon reached a larger orbit in which the impulses of expansion found an exact balance against the normal tendency of the Moon to return to its first position at the determinate orbit. Thus, supposing for the moment that the Earth could hold two satellites in stable revolution, the inner or nearer one, under the law of determinate stability, would revolve in the Moon's present orbit at 240,000 miles, while the outer or second satellite would revolve in a larger orbit situated at a determinate distance outside of the Moon's orbit. At a certain distance from the Moon's orbit, the impulses of expansion would have a continuing value just sufficient

to counteract the normal tendency of this satellite to contract its orbit to the determinate orbit. After the mass of the planet and its distance from the Sun, the fixing of the distance of the orbit of stability for the second satellite appears to depend mainly upon the relation of the periodic times—the commensurabilities, or rather, the particular phase of the incommensurabilities—of the two satellites. Within rather wide limits, the result appears to be independent of their masses, for large and small satellites revolve in adjacent orbits and obey the law without notable deviation.

7. The third, fourth, and later satellites of the larger systems are captured and installed in precisely the same way, and the spacing of their orbits, and their stabilities in them, are dependent upon the same mechanism as that just described for the second satellite. Thus, the third satellite depends upon the supporting perturbations of the second, the fourth depends on the third, and so on. Under the law of determinate stability, a new member may be acquired only by entering the space between the primary and the first or nearest established satellite, and then gradually driving all of the previously established members out to larger orbits, while it winds its own orbit down and finally settles itself in the first or determinate orbit. The space between the primary and the determinate orbit is in some sense like a vortex whirl (not a vortex ring, but a whirl), and the process of capture by this method may therefore be called *vortex capture*. *Satellite systems grow by a process of vortex capture and orbital expansion.*

8. By a simple and direct analogy, all of these principles and explanations may be applied to the Planetary system itself. It has the same dependence throughout on the law of determinate stability, has the same structure, and has grown by the same process as the imaginary satellite system just described. All of the great features and characteristics of the Planetary system come under the pervasive power of the principle of determinate stability, and are explained by it.

9. In the Planetary system, the space between Mercury and the Sun is the vortex through which all newly captured planetoids must make their entrance in order to become planets. Mercury is now oscillating around the determinate orbit, which corresponds to its mean circular

orbit, and in its relatively high eccentricity and inclination of plane, still carries marks of its newness as a planet. It has not yet become fully settled. Some of its peculiarities of motion are probably due to the action of the unbalanced forces which affect it when it is farthest inside or farthest outside of its mean circular orbit, and may not require Einstein's new theory to explain them.

Is it not clear that the mechanism of the adjustment and stability of the second satellite, as outlined above, discloses, in reality, a basis for determining the physical explanation of the Law of Titius (Bode's Law), in accordance with which the planets are set at certain orderly intervals of distance from the Sun? This law has always been a subject for mere ridicule. It is usually passed over in one sentence as "a so-called law." But under the principle of determinate stability, it is the capstone of the structure, the final completing law of systematic organization. We see its physical basis more clearly in the satellite systems, where the *scale* of each system is fixed by the mass of the primary, and the *intensity* of each system by the mass of the Sun and by the distance of the primary from the Sun. If Jupiter's mass were one-fourth of what it is its satellites would be nearer to it, and they would be more closely spaced, a more compact system. On the other hand, if Jupiter revolved in the Earth's orbit it is doubtful whether it could retain even one satellite, because the determinate orbit would be so far out. The failure of the Law of Titius in the case of Neptune is of no vital importance. The delicate forces revealed in this law grow excessively weak at that great distance, and it is not surprising that perfection of adjustment fails. The remarkable unimportance of mass in the planets as compared with commensurabilities in the operation of this law is shown by the fact that little Mars and the thinly scattered ring of tiny planetoids, though somewhat perturbed, hold their appointed places in close proximity to the mighty Jupiter.

10. The satellite zones of the planets are naturally widest far from the Sun, and the forces that hold the outer satellites of the outer planets are exceedingly weak. Nearer the Sun, the limits of the zones draw together, the inner moving out, and the outer in. This is clearly shown if all the planets be supposed to have the same mass. The Earth's zone is narrow, but that of Venus is

still narrower, too narrow probably for the capture of a satellite, the normal eccentricity of newly captured bodies being too great to be held in so narrow a space. Venus could probably hold a well settled satellite if the high eccentricity of the early stages of capture could be avoided. Mercury presents a paradox, for the limits of its satellite zone probably pass each other, the outer limit being inside of the inner limit; so it can have no satellite.

Space forbids any discussion here of the significance of the other great features of the Planetary system—the giant planets, the planetoid ring, Saturn's rings, axial rotation, the meaning of the order of these features in the system, and the simple way in which all of them unite in confirming the theory of the growth of the system by vortex capture and orbital expansion. But it is not necessary to dwell further on these things here, for in other writings I have already discussed all of them, the most extended discussion being in the small volume referred to above, entitled "The Planetary System."[4]

Fort Wayne, Ind., December 28, 1920.

[4] "The Planetary System: A Study of Its Structure and Growth." Published by the author at Fort Wayne, Ind., and by C. D. Cazenove & Son, London, in 1903; 268 pages. The discussion of determinate stability is presented in more succinct form and probably more clearly in the present paper, but the laws of satellite systems, and the process of their growth are more fully set forth in Part I of the book. The application of the principle of determinate stability in explanation of the great features and characteristics of the Planetary system are more fully set out in Part II of the book than elsewhere. Many things are presented which are necessarily omitted from the present paper, and some of them give strong support to the present hypothesis. A pamphlet of 40 pages epitomizing the same theme was printed privately in 1898 under the title, "An Endogenous Planetary System." This was a sort of caveat on the idea, and only a few copies were sent out. An earlier attempt at printing was made in 1891, when 144 pages were printed. But this effort was premature, and the printing was never completed. In all of these papers, the subject was treated by the synthetic or deductive method. In another paper prepared recently, under the title "The Growth of the Planetary System as Revealed in Its Vestiges," I have endeavored to interpret the features by the analytic or inductive method. By a study of the significance and relations of the facts alone, an effort is made to discover by what process the system has grown. Preconceived theories are avoided as far as possible. No mention is made of determinate stability, except for the purpose of reference in a footnote at the end of the paper.

Art. XIX.—*Paleobotany and the Earth's Early History*; by A. P. Coleman.

Dr. Knowlton's paper on the "Evolution of Geologic Climates," read last winter before the Paleontological Society, is full of interest to the ordinary geologist from its comprehensive summing up of the ancient history of land plants, such as only a master of the subject could have produced. Part I of his paper rouses enthusiasm with its splendid array of forests, mostly tropical, from all parts of the world, culminating in the rich Eocene flora. His account of the vegetation of the past confirms and heightens the impression left by paleozoology that during the greater part of the world's history temperatures have been genial even in the far north and far south where frigid climates now reign. Dr. Knowlton suggests that not alone were the temperatures of past ages warm, but that generally the climates were moist with hothouse conditions and with no seasonal changes until the latest periods. Annual rings are rarely found in the trees and only once before the Pleistocene is a period of severe cold admitted, in the early Permian time of glaciation, and then the cold period "was probably of short duration," and did not affect North America, Europe, or Northern Asia.

Throughout this rapid outline of the successive floras of the past there are few references to periods of cold or of drought in the world's history, and these are minimized, thus preparing the reader for Part II of the paper, in which Marsden Manson's theory of the earth's ancient climates as controlled by the earth's interior heat is advocated.

A paleobotanist naturally lays stress on the equable warmth and moisture of the earth's ancient climates, since the plants themselves thrive best under such conditions. In times of great drought or of extreme cold, such as existed during eras of great land emergence, plants are absent or rare and the chances of their preservation are poor, so that the paleobotanist finds little or no evidence of such severities of climate. The mild and moist periods are tremendously emphasized and the relatively short intervening periods of drought and cold are slurred over or entirely unrecorded by Paleobotany. It is not surprising, then, that the evidence of great cold and of

One important example of ancient banded rocks of this kind has received little attention and may be referred to specially here. The middle member of the Sudbury Series, called the McKim Graywacke, consists of thin layers of interbanded graywacke and slate, i. e., of coarser and finer particles, usually from half an inch to two or three inches in thickness. The banding has not been connected with glacial materials. As the beds are 4,000 feet thick, they indicate alternating conditions of deposit lasting thousands of years; and no theory of formation which does not include seasonal times of flood and slack water of great regularity is admissible.

These very ancient banded rocks of Canada have a parallel in the banded Bothnian rocks of Finland as described by Sederholm, who believes them to have been formed, if not in a glacial period, at least in a cold climate.

It is evident that the testimony of the world's banded slates of different ages, reaching back almost to the earliest times, must be taken seriously into account in all speculations as to the beginnings of geology.

Ice Ages.

The most impressive of all the proofs of severe ancient climates incompatible with any theory of an earth continuously cooling down until the Pleistocene to to be found in the ice ages of the far past. Whatever theory one advocates as to the cause of ice ages, it is evident that the presence of great ice sheets on low ground in several continents at once during Permo-Carboniferous times cannot be reconciled with a mild and equable climate due to the unexhausted internal heat of the earth. The presence of great ice sheets in Australia, South Africa, South America and India, as admitted by Knowlton himself, is fatal to the theory he advocates, and no suggestion that the period of cold was short affects the conclusion. While these continents were heavily glaciated, in places close to sea-level, as shown by associated marine beds, North America was frost-touched near Boston and in the Yukon region, and both France and Germany have glacial deposits that seem to be of the same age; so that all the continents were affected. Süssmilch and David's proof of three repetitions of ice invasion in New South Wales, with long intervals between them, demonstrates that glacial conditions were very long continued, though broken by interglacial intervals of moderate temperatures.

form and steady supply of heat from the earth's interior under the assumed screen of clouds. Another type of evidence, the regular banding of clays with finer and coarser layers, the "annual rings" of the rocks, he leaves as doubtful. In this, I believe, no physical geologist will agree with him. The banding of Pleistocene clays, counted by De Geer up to 12,000 annual layers in Sweden, was undoubtedly due to seasonal changes, summer and winter; and there are many instances of precisely similar banding in older rocks, sometimes associated with undoubted glacial deposits, but sometimes unconnected with known tillites. An excellent summing up of the evidence for seasonal banding of slates of various ages is given by Sayles, whose attention was directed to the subject by the occurrence of well banded slates with the Squantum tillite of Carboniferous age.[1] Where sought for, such banded rocks are usually found with the tillite of an ice age, exactly as the Pleistocene banded clays are connected with the bowlder clay of the latest glacial time. Süssmilch and David describe great thicknesses of them in connection with the wonderful Australian glacial and interglacial deposits of late Carboniferous and early Permian times. At Seaham, New South Wales, for instance, such banded beds are held to indicate 3,000 years of deposit in a glacial lake. Their figures and descriptions leave no doubt as to the origin of the shales, since they are entirely similar to the banded clays (*varve* clays) of the Pleistocene.[2] Similar banded slates, sometimes enclosing ice-rafted bowlders, are found with the Cobalt tillite, of Huronian age; and no doubt other examples of the sort will be found when geologists have their attention directed to the subject in glacial deposits of other ages and in other parts of the world.

It may be looked on as proved, then, that the year had warm and cold seasons in the late Carboniferous and Permo-Carboniferous; and also in the Huronian glacial times.

If this is true of the regularly banded sediments occurring with tillites, there is reason to believe that similar banded sediments no tknown to be associated with bowlder clay, had a corresponding origin. Sayles would even make the banding evidence of glaciation.

[1] R. W. Sayles, Seasonal Deposition in Aqueo-glacial Sediments, Mem. Mus. Comp. Zool., Harvard, vol. 43, No. 1, 1919.

[2] Proc. Roy. Soc., New South Wales, 53, 270, 1919-20.

ART. XX.—*Evolution of Geologic Climates;* by CHARLES SCHUCHERT.

Under the above title, F. H. Knowlton has written a most interesting paper,[1] the thesis of which is the following:

"Relative uniformity, mildness, and comparative equability of climate, accompanied by high humidity, have prevailed over the greater part of the earth, extending to, or into, polar circles, during the greater part of geologic time—since, at least, the Middle Paleozoic. This is the regular, the ordinary, the normal condition" (p. 501).

In another place we read:

"By many it is thought that one of the strongest arguments against a gradually cooling globe and a humid, non-zonally disposed climate in the ages before the Pleistocene is the discovery of evidences of glacial action practically throughout the entire geologic column. Hardly less than a dozen of these are now known, ranging in age from Huronian to Eocene. It seems to be a very general assumption by those who hold this view that these evidences of glacial activities are to be classed as ice ages, largely comparable in effect and extent to the Pleistocene refrigeration, but as a matter of fact only three are apparently of a magnitude to warrant such designation. These are the Huronian glaciation, that of the 'Permo-Carboniferous,' and that of the Pleistocene. The others, so far as available data go, appear to be explainable as more or less local manifestations that had no widespread effect on, for instance, ocean temperatures, distribution of life, et cetera. They might well have been of the type of ordinary mountain glaciers, due entirely to local elevation and precipitation" (pp. 547-548).

And again:

"If the sun had been the principal source of heat in pre-Pleistocene time, terrestrial temperatures would of necessity have been disposed in zones, whereas the whole trend of this paper has been the presentation of proof that these temperatures were distinctly non-zonal. Therefore it seems to follow that the sun—at least the present small-angle sun—could not have been the sole or even the principal source of heat that warmed the early oceans" (p. 547).

Doctor Knowlton naturally lays greatest stress in his conclusions upon the paleobotanic evidence, because it is this knowledge that he and his associates at Washington

[1] Bull. Geol. Soc. America, 30, 499-565, 1919.

have so well in hand. However, that not all of his colleagues are in harmony with his views is shown by the following quotation from Wieland:[2]

"Does not a larger part of the Jurassic Ginkgo record also indicate wide climatic variation, second only in extent to that of the time of the Glossopteris flora? Would it not be singular if plant evidence remained wholly at variance from that of the insects and invertebrates, indicating climatic cooling in the late Trias and early Jura, not local in character?" And A. G. Nathorst is quoted by Wieland as saying that "during the time when the Ginkgophytes and Cycadophytes dominated, many of them must have adapted themselves for living in cold climates also. Of this I have not the least doubt."

Knowlton knows that certain invertebrate evidence which he quotes from the writer and to which Wieland in the above quotation refers, indicates that toward the end of Triassic time and early in the Jurassic there were winters, about as they are now, in the latitudes of England to South Germany. In this connection it may be well to quote from still another paleontologist. Ulrich says:[3]

"Doubtless even in the Paleozoic there were times of relative frigidity—when some of the higher parts of the marginal lands were ice-covered, in some instances attaining locally to glacial conditions. Here and there regular tillites are indicated, notably, as recently brought out by Dr. Edwin Kirk, in the Silurian deposits along the coast of Alaska."

A careful reading of Knowlton's paper leaves the writer with the impression that the former holds that, except for the early Huronian, early Permian, and world-wide Pleistocene glacial times, the earth has been without temperature zones and large arid tracts, and that in general humidity has prevailed. Any paleontologist who is familiar with the climatic aspects of fossils will probably have to agree with Knowlton that the biotic evidence, and chiefly that of the floras, does in general bear out his conclusion that "climatic zoning such as we have had since the beginning of the Pleistocene did not obtain in the geologic ages prior to the Pleistocene." But what Knowlton actually holds is that there was "a non-zonal arrangement [of climate] prior to the Pleistocene" (p. 541), and that the temperature of the oceans was everywhere the same and without "wide-spread effect on the distribution of life" (p. 548).

[2] G. R. Wieland, Amer. Jour. Botany, 7, 154, 1920.
[3] E. O. Ulrich, Jour. Washington Acad. Sci., 10, 67, 1920.

What Knowlton sees so well are the wide-spread fossil floras that usually occur in the middle portion of the geologic periods when the transgressions of the warm-water oceans over the continents are greatest; in other words, those times when the lands are smallest and are dominated by insular and therefore equable climates due to the wide-spread and warm oceanic waters. But what were the climatic conditions during the early and late parts of the many periods when the continents were largest, highest, and most arid? And it is at some of these times when the local or the widely spread tillites were forming!

That the oceanic waters were not everywhere and during most of geologic time equably warm is attested by the varied life distribution seen in the large colonial foraminifers, stony corals, shelled cephalopods, and thick-shelled bivalves (chiefly the cemented forms) and gastropods. We see some or all of these groups of animals common in the far north and even in arctic waters during the Silurian, Devonian, Pennsylvanian, and Jurassic, but at other times they are either greatly reduced in variety in these regions or almost or completely absent. Take the Cretaceous foraminifers, sponges, corals, and rudistids, and the late (but not latest) Eocene nummulids, and see how they drop out of the record as one proceeds toward the Arctic. In India, nummulites attain to a diameter of eight inches, but in Japan they are all small, and north of Japan there are none of them at all. Moreover, the giants of any stock are rarely seen in far northern waters. These things can only mean temperature differences, and that the northern waters were frequently under 65° F. And if the oceanic waters were thus variable in temperature from time to time and from place to place, we may conclude that the climates of the lands were also varied and had zonal belts.

On the other hand, when the lands are largest and the marine faunas localized in small sea-ways not widely accessible to the paleontologist, where are the cosmopolitan faunas and the large forms, and where is the variety and abundance of foraminifers, corals, bryozoa, cemented and thick-shelled molluscs, and shelled cephalopods? Exceptions there are, of course, but in general the restricted formations have small faunas and small species that are more or less unrelated to one another. In other words, we have here the stress-assemblages in which a prolifera-

tion of species and genera is beginning, along with the introduction of biotic lines that are to lead to the terminal giants. It is true that in these stress-faunas some of the handicaps of the environment are due to physical causes other than temperature, and yet the chief deterrent seemingly was the lack of the proper warmth. What kills off the giants? In some cases it is old age within the stock, but in many others it apparently is change in the environment, the deciding factor in which appears to be temperature.

The evaluation of sediments for climatic purposes has not yet gone very far, nevertheless it is well known that limestones are far more readily deposited by the life of the warm waters than by those of cold ones. The great limestone-making areas of to-day are in the warm waters. Moreover it ought to be well known that the greatest amount of limestones, and especially of magnesian limestones and dolomites, does not occur in polar lands but rather in the temperate and subtropical ones. At times they are of extremely wide geographic distribution, as are the magnesian limestones and dolomites of the Ozarkian and early Ordovician, and those of the middle Silurian, middle Devonian, and middle and late Pennsylvanian—times when the earth's climates are recognized by general agreement as mild throughout most of the northern hemisphere. Why is it that pure limestones and dolomites are less prevalent at other times during the Paleozoic and even within the latitude of the United States? In some cases it is undoubtedly because of the too great prevalence of muds and highlands, but in others it appears to be due to a temperature condition.

In 1918, Blackwelder published a short but very striking paper entitled "The climatic history of Alaska from a new viewpoint."[4] The viewpoint is that of the sediments, and one is impressed with the abundance he records of sombre and dark colors, muddy sandstones, and silts, and undecomposed mineral clastics, the scarcity of limestones, and the almost total absence of red colors. From the evidence recited Blackwelder concludes:

"The combined evidence strongly suggests that the cool, moist climate of modern Alaska,—oscillating now and then toward the glacial Arctic condition on the one hand and toward the moist temperate on the other,—has been persistent, with but few real interruptions, throughout the known geologic history of Alaska."

[4] Eliot Blackwelder, Trans. Illinois Acad. Sci., 10, 275-280.

When zoo-paleontologists have more clearly evaluated the climatic significance of the varied geographic marine faunas known to them, and geologists have learned the temperature import of the great variability in marine sediments, the conclusion will all the more certainly be drawn that the earth throughout the geologic ages has been subject to climatic variation. These variations will be seen to be slightest, indeed very slight, during the middle parts of the geologic periods when the world has almost no temperature belts; and variably greatest during their earliest and latest parts, when more or less marked climatic zones and even glacial climates were developed. To-day the variation on land between the tropics and the poles is roughly between 110° and —60° F., in the oceans between 85° and 31° F. In the geologic past the temperature for the greater parts of the periods of the oceans probably was most often between 85° and 55° F., while on land it may have varied between 90° and 0° F. At rare intervals the extremes were undoubtedly as great as they are to-day. The conclusion is therefore attained that throughout its history the earth has had temperature zones, varying from an intensity as marked as that of to-day to almost complete absence so that the greater part of the earth had an almost uniformly mild climate, without winters.

ART XXI.—*The American Bothriodonts;* by EDWARD L. TROXELL.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

INTRODUCTION.

Seldom do we find instances of genera that have been so variously arranged and classified, or a synonymy and precedence that have been more discussed than those of the group of extinct artiodactyls which constitute a part of the Anthracotherinæ, including the well known names: *Ancodus* Pomel, *Bothriodon* Aymard, *Elomeryx* Marsh, *Heptacodon* Marsh, *Hyopotamus* Owen, and *Octacodon* Marsh. In the present study it has been necessary to use our own American generic names, adding one new one, in order to bring out the distinctions, from the European forms, which exist in every case; but one can not resist the impulse to attempt to settle the Old World difficulties, and matters of synonymy are no exception.

Bothriodon (*Ancodus, Hyopotamus*).—The generic name *Ancodus* Pomel was made in June 1847, that of *Hyopotamus* Owen[1] in November of the same year. For years it was supposed that *Bothriodon* Aymard was made in 1848, until Miss Lucy P. Bush[2] set forth a very clear explanation of the matter, backed up by evidence to show that Aymard's publication was not of 1848 as appears on the cover, but of 1846, thus giving his genus the priority. A difficulty raised by Peterson[3] about the page reference in Aymard's paper to a publication by Pomel dated December 21, 1846, may be explained in one of two ways: first, Aymard's paper came out during the last nine days of December, 1846; or second, Aymard had access to the printer's proof of the other paper before December 21. The latter explanation is the more plausible, because the two authors, Pomel and Aymard, appear to have been working in entire harmony.

Because of these circumstances, it seems necessary

[1] W. D. Matthew (Bull. Amer. Mus. Nat. Hist., vol. 26, 6, 1909) states that this genus is preoccupied by *Hyopotamus* Kaup 1844, a genus of supposed Hippopotamidæ not now recognized.

[2] L. P. Bush, this Journal (4), 16, 98, 1903.

[3] O. A. Peterson, Mem. Carnegie Mus., vol. 4, No. 3, p. 43, 1909. Peterson here erroneously states that Pomel's article in the Bulletin de la Société Géologique came out late in 1847. The article itself bears the date of December 21, 1846.

to re-adopt the name *Bothriodon* Aymard (syn. *Ancodus* Pomel, *Hyopotamus* Owen) in agreement with Professor Marsh and Miss Bush. Nor is it a misfortune to follow Aymard in this respect, for it is to him we have to turn for the early descriptions of this group of the anthracotheres. Kowalevsky[4] says in 1874:

> "The priority . . . is claimed by Pomel . . . but as he neither gave a good description . . . , nor illustrated his short notices by figures, no paleontologist has accepted this name, and it may be considered extinct."

He therefore proceeds to use the name *Hyopotamus* instead.

Filhol,[5] although he continues to use the term *Ancodus*, yet agrees that we owe it to the researches of Aymard alone, carried on so long at Ronzon, that we have the necessary material to trace the group completely.

Relationship to foreign types.—It is not profitable at this time and in such a paper as this, to go deeply into the study of the Old World faunas. Kowalevsky,[6] after comparing the British specimens of *Hyopotamus* with those of *Bothriodon (Ancodus)* of the continent, says that he can find no noteworthy distinctions. But in the seemingly great variety of European forms, it is evident that no one genus can be so broad as to include all the species, and one is led to believe that a careful study would establish the authentic separation of *Bothriodon* and *Hyopotamus* at least, and might even create the need for additional genera. In fact, there seems to be nearly as much difference between *H. bovinus* Owen and *H. vectianus* Owen as there is between the latter and some species of *Elomeryx*, and doubt lingers as to whether even the two English forms should be included under the same head.

Description of Genera.

Anthracotherium Cuvier.—The distinctions between certain New and Old World forms are listed under the description of *Æpinacodon*, gen. nov., later. The differentiation of *Anthracotherium*, *A. magnum* Cuvier, may here be briefly set forth: It is a very large animal ranging in size to a half larger than our American forms, as shown by De Blainville. P^3 has a heavy deuterocone

[4] W. Kowalevsky, Philos. Trans. Roy. Soc. London, 163, 22.
[5] H. Filhol, Ann. Sci. Géol., 12, art. 3, 191, 1881.
[6] Op. cit., p. 23.

like that of P[4] and on the lower jaw there is a tubercle under P_4 like those of the entelodonts. In few respects does this genus resemble even the Old World bothriodonts, and it is widely different from those of the western hemisphere.

Heptacodon Marsh.

(Fig. 1.)

Genoholotype, *H. curtus* Marsh. Upper Oligocene (Protoceras beds), Phinney, South Dakota.

The original description of *H. curtus* is as follows:[7]

"A very perfect last upper molar, which may be taken as the type, is shown natural size in the accompanying figures. Its crown is composed of the same main elements as in the corresponding tooth of *Hyopotamus*, but all the five cusps are much

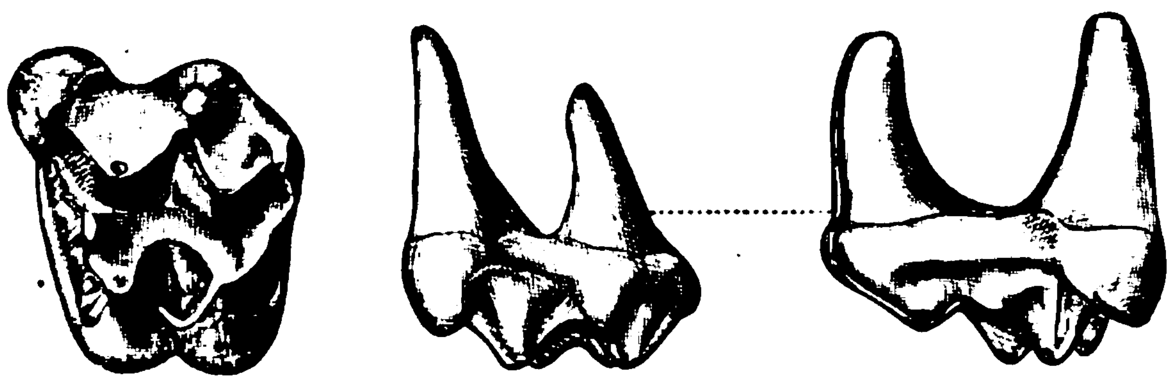

Fig. 1.—*Heptacodon curtus* Marsh. Holotype. Cat. No. 11803, Y. P. M. Crown, side, and front views of M[3]. After Marsh. Nat. size.

less elevated. In addition, the basal ridge of the outer margin is swollen into two high pointed cusps, making seven in all, and this has suggested the generic name.

"Of the outer cusps, or buttresses, the anterior one is the larger, and is situated well forward and partly outside of the main body of the crown. The antero-median cusp is well developed, triangular in outline, and situated somewhat in advance of the other two anterior cusps. . . . The two interior cones are connected near their margins by a low ridge, and their summits are joined by a high outward-curved ridge, which extends nearly to the centre of the crown. The crown itself is very short, considerably shorter than in the molars of *Hyopotamus*.

"The animal thus indicated, which may be called *Heptacodon curtus*, was somewhat larger than a sheep. The known remains are from the upper Miocene of South Dakota."

This specimen, probably the second upper molar (see fig. 1), as shown by wear on the posterior side, is markedly distinct from any other specimen at hand and bears

[7] O. C. Marsh, This Journal (3), 47, 409, 1894.

little resemblance to *Anthracotherium magnum* Cuvier, in form or size. Briefly its distinctive features are as follows: absence of cingulum except on the anterior side; the bases of the proto- and hypocone equal; these two cones joined by two ridges inclosing a deep short segment of the transverse groove; the proto-conule weak; the para- and metacones most prominent of all the moderate cones; ridges from them joining one from the mesostyle to form a Y as in *Octacodon;* the parastyle very prominent, with a sharp cusp, and widely separated from the mesostyle; the metastyle almost obsolete. The dimensions are: antero-posterior, 19.5 mm. on outer border, and transverse, 21.5 mm. on anterior side.

Octacodon Marsh.

This genus, having for its genoholotype *O. valens* Marsh, should also include, it seems, *Heptacodon gibbiceps* Marsh and *Anthracotherium karense* Osborn and Wortman,[8] for reasons set forth on the following pages. All are of the Protoceras beds and all conform in important details to the genoholotype.

Octacodon valens Marsh.

(Fig. 2.)

Holotype, Cat. No. 11860, Y. P. M. Upper Oligocene (Protoceras beds), Hermosa, South Dakota.

The type specimen consists of the third upper molar (see fig. 2) and an incisor, and was described by Marsh as follows:[9]

"The tooth represented . . . may be regarded as the type of the present genus and species. It is the last upper molar of the right side, and is in fine preservation. The slight wear of the tooth shows that the animal was adult. There are five main cusps in the crown, two on the posterior half, and three on the anterior, the antero-median cusp being the smallest. On the outer margin of the tooth are three prominent buttresses with conical summits, making in all eight prominences on the crown, which feature has suggested the generic name.

[8] H. F. Osborn and J. L. Wortman, Bull. Am. Mus. Nat. Hist., vol. 6, 221-223, 1894. The referred specimen of these authors, *A. curtum* (Marsh), No. 1039 American Museum Collection, can not be considered the same as *Heptacodon curtis* Marsh (see *Heptacodon* above), but should in all probability be placed with *Octacodon*, cf. *O. gibbiceps*, in spite of its earlier age.

[9] O. C. Marsh, This Journal (3), 48, 92, 1894.

"The three conical buttresses on the outer border of this tooth, all strongly developed, will serve to distinguish it from the corresponding molar of *Hyopotamus,* which in several respects it resembles. In that genus, the main cusps are much more elevated. *Heptacodon,* perhaps an allied form, has a similar buttress at the anterior angle, but none at the posterior. An upper incisor found with the present tooth, and doubtless pertaining to the same individual, has a very short, compressed crown, with a strong inner basal ridge, making the inner face deeply concave."

The low cusps, absence of cingula excepting a weak one anteriorly, the prominence of the three styles, and especially the para- and mesostyles, the shallowness of the transverse valley which ends between the para- and metacone, the distinct ridge from the cusp of the mesostyle forming a Y with ridges from the para- and meta-

Fig. 2.—*Octacodon valens* Marsh. Holotype. Cat. No. 11860, Y. P. M. Crown view of M[3]. After Marsh. Nat. size.

cones, the short antero-posterior and the great transverse diameter anterior, and the general smoothness, are all features which separate the species from those of any other genus.

Octacodon gibbiceps (Marsh).

(Fig. 3.)

Holotype, Cat. No. 10194, Y. P. M. Upper Oligocene (Protoceras beds), Hermosa, South Dakota.

The original description, under *Heptacodon,* is in part as follows:[10]

"The facial portion of this skull is strongly rounded above, especially in the frontal region, and this has suggested the specific name. The orbits are large, and not closed behind, although limited posteriorly by strong processes above and below. There is no antorbital depression, and the lachrymal foramen is inside

[10] O. C. Marsh, This Journal (3), 48, 175-176, 1894.

the orbit. The nasals are elongate, narrow in front, and widely expanded behind where they join the frontals. They touch the lachrymals, thus separating the maxillaries from the frontals.

"There were in all forty-four teeth. Three incisors were present on each side above, and there is a diastema behind the last one. The upper canine was large, and directed well forward and outward. There is no diastema behind the canine, and the four premolars form with the true molars a continuous series. The first and second premolars are secant, the third is subtriangular in outline, while the fourth has its crown composed of one external cusp and one internal cone. . . .

"The posterior nares open opposite the middle of the last upper molars. The anterior palatine foramina appear to be confluent, forming together a heart-shaped aperture, which may in part be due to injury."

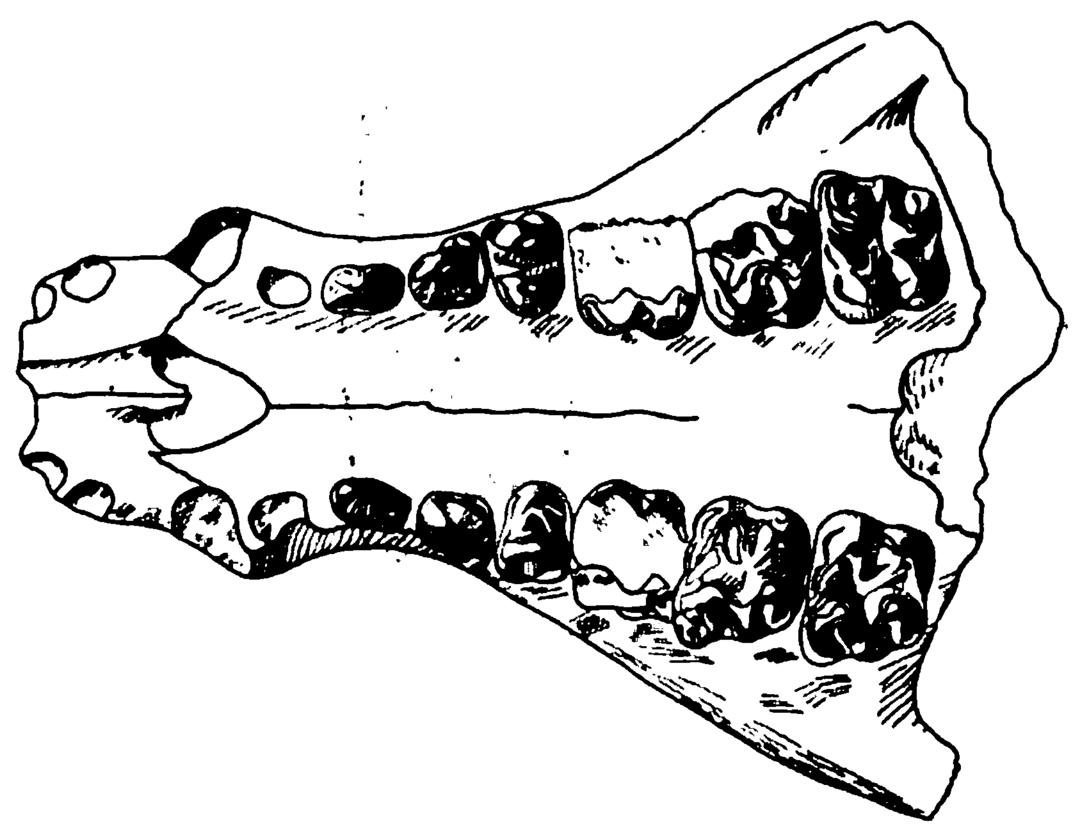

Fig. 3.—*Octacodon gibbiceps* (Marsh). Holotype. Cat. No. 10194, Y. P. M. Palatal view of skull. × 1/3.

In so far as M^3 of this specimen (see fig. 3) has low cusps, weak cingula, general smoothness, failure of transverse valley to cut into the mesostyle—showing a ridge instead, a great anterior diameter, and especially by its general contour, it is seen to be very closely related to the type of *Octacodon* Marsh, to the exclusion of other genera.

The differences are minor, comparatively, but are sufficient to distinguish the two species: of *O. gibbiceps* we note the weaker styles without sharp separation, the faint cingulum both outside and back of the hypocone, the less deep valleys, and the strong ridge from hypocone to the center of the tooth.

Other features, shown by this completer skull, will serve to establish the genus more broadly. M^2 is nearly equal to M^3 and has the same form; M^1 is slightly smaller; the cusps of P^4 are not tall but the deuterocone is broad at the base, the anterior and posterior sides of the tooth are symmetrical; P^3 is very broad anteriorly and squared, and the inner shelf is weak; a strong postero-exterior fold constitutes the tritocone; P^2 is oblong due to the very wide anterior edge and the absence of an inner shelf or deuterocone. The absence of diastemata around P^1, the shorter, broader face, and the position of the posterior nares opposite M^3 are very distinctive of the species and probably of the genus.

Elomeryx Marsh.

(Fig. 4.)

Genoholotype, *E. armatus* (Marsh). Upper Oligocene (Protoceras beds), Hermosa, South Dakota.

The species *E. armatus* Marsh was first described under *Heptacodon* Marsh as follows:[11]

"Figure 2 [our fig. 4] . . . represents natural size the last right upper molar of another large ungulate mammal, the exact

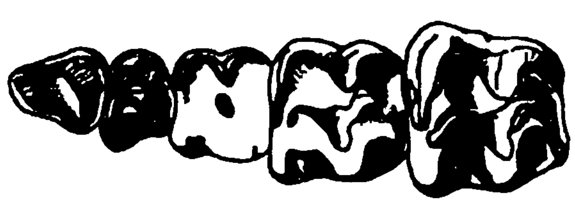

Fig. 4.—*Elomeryx armatus* Marsh. Holotype. Cat. No. 10176, Y. P. M. Crown view of upper molars and premolars. × 1/3.

affinities of which can not now be determined. This tooth is considerably worn, showing that it belonged to an old animal. The remaining molars and part of the premolars in the same series are preserved, and with them a very large canine still in position in the jaw. All are worn, but otherwise in good preservation. The tooth figured has a crown composed of five main cusps, the antero-median being the smallest. The outer buttresses are of moderate size, and there is none at the posterior angle. The enamel of this tooth and of all the series is rugose. The true molars differ greatly in size, the first being quite small, the second intermediate, and the last equal in bulk to the two others.

"The last premolar has one outer and one inner cusp. The next tooth in front is larger, and has a triangular crown, and the next is close to it. The canine is very large, dependent, and oval in section. Behind it is a long diastema."

[11] O. C. Marsh, This Journal (3), 48, 93, 1894.

Later[12] there was made a new genus *Elomeryx*, and the description of the species was thus amplified from skulls in the collection (Cat. Nos. 10177 and 10195):

"The specimen described . . . as *Heptacodon armatus* proves on examination to belong to a distinct genus, which may be called *Elomeryx*. . . . Some of the main characters are as follows:—The skull is elongate, with the facial part quite narrow. The frontal region between the orbits is flat or even concave. The orbits are very small, and not closed behind. There is no lachrymal fossa. The anterior narial opening is large, and the snout broad.

"There are the usual forty-four teeth. The upper incisors diverge, and have short, compressed crowns. The upper canine is very large and dependent. It is oval in outline near its base, but compressed below, with a serrated posterior edge; a feature not before observed in ungulate mammals. There is a long diastema behind the canine. The premolars and molars form a close series. . . .

"The posterior nares are placed well behind the molar series, much as in existing swine. There is a postglenoid process, and a long paroccipital. The type species has a small auditorial bulla, and the other, a larger one. The zygomatic arch is slender, and curved well outward. The temporal fossæ are large, and separated above by a narrow sagittal crest. The brain was well developed. The type specimen of *E. armatus* indicates an animal about the size of a large deer."

Additional characters of the type of *E. armatus* are here given in contrast to another specimen made the type of a new subspecies on a later page.

Character	*E. armatus armatus* Cat. No. 10176	*E. armatus angustus* Cat. No. 10393
P^3 diameters	16 × 19 mm., wide	14.5 × 20.5 mm., narrow
P^4 diameters	20 × 15 mm.	20.5 × 15 mm.
form, ant.	Convex, inner half oval	Concave, anterior and posterior sides parallel
M^1 cingulum	Internal basal cusp Cingulum on base of hypocone	Encircles hypocone, broken on protocone
parastyle	Moderate, weak groove posterior	Very large and prominent indentation posterior
M^2 cingulum (internal)	Int. basal ridge. Proto- and hypocone smooth	Encircles hypocone, broken on protocone
parastyle	Weak	Marked by strong groove
M^3 cingulum	Int. basal ridge. Proto- and hypocone smooth	Extends onto and around hypocone, broken on protocone
styles	Not prominent	All large, prominent, and well separated by grooves

[12] O. C. Marsh, This Journal (3), 48, 176-177, 1894.

In the large number of skulls in the Marsh Collection the genus *Elomeryx* shows the greatest variation, including a specimen of *E. brachystylus* Osborn and Wortman (Cat. No. 10387, Y. P. M.). The canine has lengths of from 10 mm. to 45 mm. One has a choice of calling this a sex feature or of considering the specimens as widely separated and distinct; the former seems more probably correct. The postcanine diastema varies from 20 mm. to 35 mm. and its length bears no relation to the size of the canine. The second premolars may vary from 9.5 to 13.5 mm. in width, the lengths are constantly around 16 or 17 mm. As already shown, the third premolars have various lengths and widths and many differences in the nature of the triangular crown.

Other eccentricities are shown in the table above. A rather important feature, characteristic of neither of these specimens, is the position of the cingulum running up the side of the hypocone; in the types just compared, the cingulum either ends abruptly (*E. armatus*), or is continuous around the base of the cone. There is great diversity to be seen in the form of the styles, especially the metastyle, and in the depth of the notches separating them.

Minor skull variations affect the width, pointedness and curvature of the postglenoid processes, the form and separation of the occipital condyles, the groove on the ventral side and other cranial features.

The extreme position of the posterior nares set far behind the molars, the elongation of the cranial portion of the skull, and the development of the wide shelf of bone immediately behind the last molar seem to depend on old age; but we have to look to the immature animal for the greatly inflated auditory bullæ.

In only one instance in the collection are there found the complete lower jaws belonging to a skull. This is a slender animal with canines less than 10 mm. in their longest diameter, the symphysis being weak and the whole structure light. This specimen (Cat. No. 10391, Y. P. M.) has a particular value in the study of the wear of the teeth, for we find the upper P^4 quite unworn, while the P^3 and M^1 on either side have lost nearly all the enamel from the crowns. The consequence is that in the lower jaw M_1 and the posterior half of P_4 are worn down in a deep transverse groove.

The teeth are so short crowned and so little protected

by enamel that, once the wearing starts, the tooth goes rapidly, allowing the one opposing to remain practically uneroded.

Elomeryx armatus angustus, subsp. nov.

(Fig. 5.)

Holotype, Cat. No. 10393, Y. P. M. Upper Oligocene (Protoceras beds), Hermosa, South Dakota.

This new subspecies may be distinguished by the moderately long postcanine diastema, 25 mm.; the very narrow P^2, 9.5×16 mm., and P^3, 14.5×20.5 mm. P^4 is of moderate proportions, concave anteriorly, and has a shallow, narrow longitudinal groove. On the molars the cingula surround the hypocones and, except for slight breaks, the protocones. The styles on the outer sides of the molars are well marked by deep indentations and on M^3 all are prominent. The transverse valley curves backward strongly and ends in a narrow angle on the mesostyle.

The postglenoid process is rather narrow, pointed, and does not curve strongly forward. The occipital condyles are not wide nor thick, but the median ventral groove is broad. The moderate otic bullæ and the little worn teeth show an animal just reaching maturity.

This specimen differs from the type of *E. mitis*[13] in that the latter has no cingula on the internal slopes of the hypocone and protocone and also has a weaker, more pointed parastyle with a single groove and no secondary cusp on its posterior side.

Æpinacodon,[14] gen. nov.

A name is proposed at this time for a genus to include those American forms widely separated from *Elomeryx*, *Octacodon*, and *Heptacodon* Marsh, and may include *Hyopotamus americanus* Leidy 1856, *H. deflectus* Marsh 1890 (the genoholotype), and *Ancodon rostratus* Scott 1895.

These constitute a group of bothriodonts of a much

[13] The main feature on which this species was made—its smaller size—was chosen as a result of a misinterpretation on the part of Professor Marsh. His so-called first molar is the last deciduous tooth, as proved by the presence of P^4 underneath it. Therefore the last tooth present is M^2 and is found to be as large as that of the genoholotype. It is worth noting that the last milk tooth is molariform in every respect.

[14] Αἰπεινός, high; ἀκή, point; ὀδούς, tooth.

earlier age than the genera from the Protoceras beds (*Elomeryx, Octacodon, Heptacodon*). *Æpinacodon rost-*

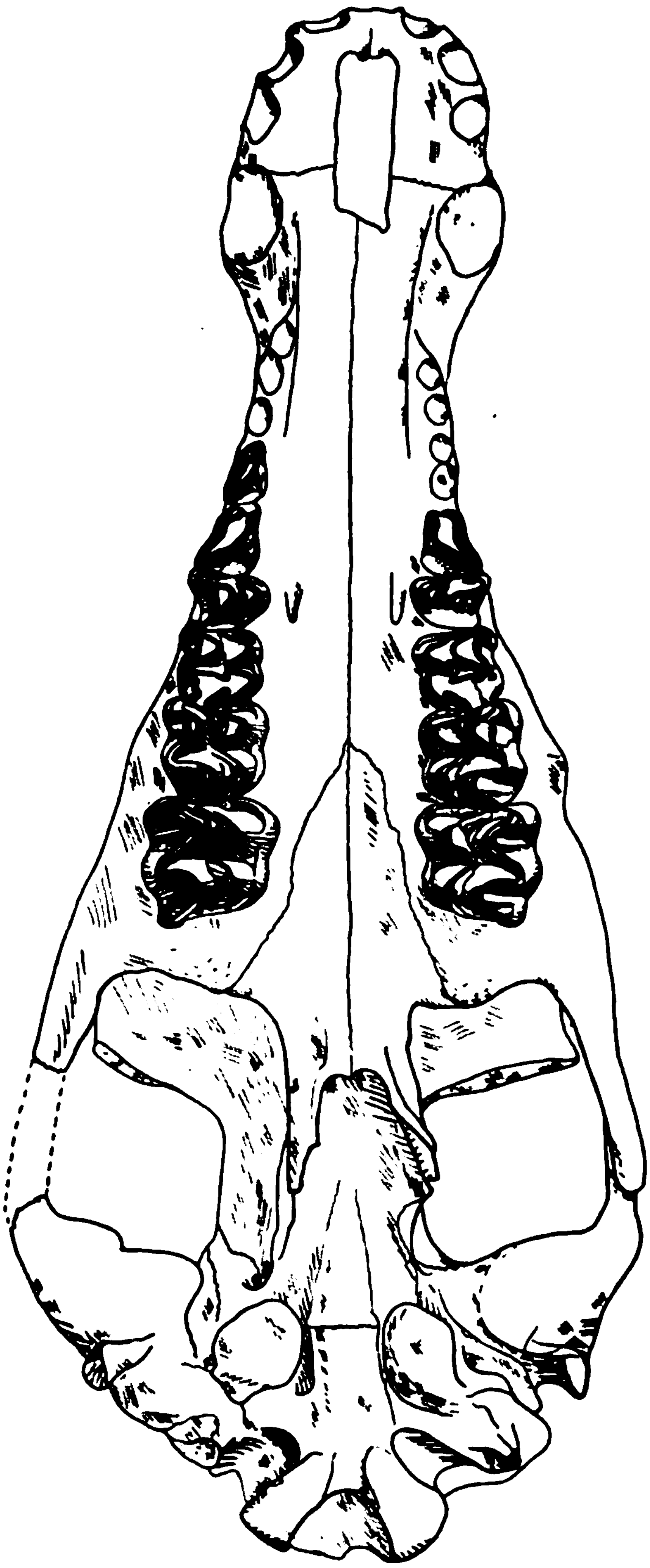

FIG. 5.—*Elomeryx armatus angustus*, subsp. nov. Holotype. Cat. No. 10393, Y. P. M. Palatal view of skull. $\times 1/3$.

ratus (Scott) comes from the Metamynodon sandstones (lower Oreodon beds);[15] *A. deflectus* (Marsh) from the

[15] *Hyopotamus americanus*, referred specimen, is also from the Metamynodon stratum. See Osborn and Wortman, op. cit., p. 220.

Titanotherium beds near Deadwood, South Dakota; and *A. americanus* (Leidy), as reported by Hayden, was found in association with *Titanotherium* remains. The age of the genus, therefore, is near the border line of the Middle and Lower Oligocene.

Generic characters.—Of the foreign types *Æpinacodon* resembles most *Hyopotamus* (*H. bovinus* Owen), but from this it can be distinguished by the curved transverse groove and the resulting decrease in size of the hypocone, by the closer grouping of the cusps transversely, by the narrower mesostyle, and by the greater relative length of the molars antero-posteriorly. *H. vectianus* Owen

FIG. 6.—*Æpinacodon deflectus* (Marsh). Holotype. Cat. No. 11802, Y. P. M. Crown view of upper molars and premolars. × 1/3.

resembles *Elomeryx* in some respects more closely than it does the new genus.

As compared to *Bothriodon* Aymard, one has difficulty in finding the resemblances; these distinctions, however, may be noted: the unreduced premolars, and absence of diastema behind P^2, the curved transverse valleys of the molars, their narrower outer borders, the grouped cusps, the rougher character with an abundance of tubercles and cingula, the less elongated muzzle, the less forward position of the posterior nares, the more completely inclosed orbit, and the narrow supra-occipital of *Æpinacodon.*

As distinct from *Elomeryx*,[16] the upper molar teeth have squared outer edges, the styles are more nearly equal, the cusps are tall and sharp, the deuterocone of P^4 is a cone, not a crescent, the teeth are all much more rugose, with numerous cusps and cingula, P^1 is generally

[16] See under *Octacodon* and *Heptacodon* the distinctions of *Æpinacodon* from these genera.

absent, a long diastema separates C^1 from P^2, the posterior nares are far forward, and the skull is narrow.

Æpinacodon deflectus (Marsh).

(Figs. 6, 7.)

Holotype, Cat. No. 11802, Y. P. M. Oligocene (Titanotherium beds), near Deadwood, South Dakota.

This species,[17] made by Marsh in 1890,[18] can now be

Fig. 7.—*Æpinacodon deflectus* (Marsh). Holotype. Cat. No. 11802, Y. P. M. A, crown view of lower molars and premolars. B, top and side view of lower canine. $\times$ 1/3.

more clearly defined. As contrasted with *A. americanus* (Leidy), one sees on M^3 that the transverse groove ends in a square, is not pointed between the para- and metacones, and the edge is crenulated or cleft deeply; the cingulum on the posterior side of the hypocone is faint or absent, while the main posterior cingulum is continuous with the ridge from its apex; an internal basal cusp or cingulum appears on the hypocone and strong ridges also from the protocone descend into the valley. The protocone is not conical but is selenodont due to its heavy ridges; the protoconule is near the protocone.

Carrying this contrast with *A. americanus* to the second molar, we find in *A. deflectus* the very strong internal basal cingulum extending quite around the hypocone; on the right M^2 the protocone and hypocone are joined by a strong ridge and on this tooth there is a wide groove between the meso- and metastyles. P^4 is a heavy tooth with strong cingula and styles; the cingulum, which is posterior, leads around the deuterocone and not onto it, leaving the latter truly a cone, round in cross-section.

[17] From the meagre description of *A. rostratus* (Scott) (Journ. Acad. Nat. Sci., Phila., 9, appendix, p. 536, 1894), these distinguishing features may be noted: P^4 of this species has a cingulum upon the inner side of the crown and the buttresses or styles are less conspicuous. The molar length is equal to that of *A. deflectus*, 71 or 72 mm. A close comparison of the types of these two species is not practicable at this time, but additional points should be had of *A. rostratus* in order to separate it clearly from *A. deflectus*.

[18] O. C. Marsh, This Journal (3), 39, 525, 1890.

This cingulum is broken on the inner surface. P^3 is very rugose, with a strong external cingulum leading to the well marked tritocone and forming a double ridge anteriorly on the protocone.

A. deflectus can be further characterized, in general, by the form of P^2 with its external cingulum, small cuspid dueterocone, and its rounded anterior and pointed posterior ends; by the boldness of the teeth in the manner in which the cusps and cingular ridges stand out; by the position of the posterior nares situated just back of the molars; by the long diastema in front of P^2 and the probable absence of P^1.

Very extensive lateral crushing has taken place in this type specimen but it is evident that the skull was very narrow originally; across between the orbits the distance is scarcely more than 70 mm. The otic bullæ are elongated antero-posteriorly; the occipital condyles are light, and the supra-occipital is narrow (22 mm.). The face is bent down strongly on the basicranial axis. The paroccipitals form peculiar, strong ridges outside the paramastoid processes; the slender processes are near the condyles and join the bullæ at their bases. The sutures between the frontals and parietals are not marked by ridges. Marsh has pointed out that the postorbital processes are long and more nearly close the orbit behind than is usual.

The lower jaws of *A. deflectus* (fig. 7) are most interesting in the number of small tubercles and interrupted cingula around and between the lobes of the teeth. The purpose of these seems to be to retard the movement of food when the long points of the superior molars press down between the lobes.

On the inner side of the talonid of M_3 is a cingulum made up of a series of cusps; the talonid itself is a single isolated pointed cone. Two exterior basal tubercles lie between the talonid and hypoconid; they appear less conspicuously between the protoconid and hypoconid. Small roughened areas break the transverse valleys and unite adjacent lobes in each case, while a strong cingulum lies anteriorly on the tooth.

P_4 likewise has an irregular lot of tubercles forming the heel and has sharp ridges running to the point of the protoconid; only the outer side of this cone is smooth. The paraconid marks the beginning of the sharp ridge to the central cone. The tooth measures 21.3×13.7 mm.

P_3 is narrow with two straight ridges running to the

tip of the protoconid. On each side of the posterior ridge are depressions bounded below by the basal cingulum. The diameters are 20 × 9 mm. P_2 is not preserved, but the two rootlets indicate its small narrow form. P_1 was entirely lacking, or was set near the canine in front of a long diastema, as is indicated by other specimens at hand.

The canine (fig. 7 B) has a very unusual form, which may be considered a flattened cone, with three strong ridges from the front, inner and back sides joining at the apex. Its diameters are 14.6 and 12 mm., the enameled crown being 22 mm. long.

Summary.

The weight of the evidence seems to show that Aymard's genus *Bothriodon* precedes *Ancodus* Pomel and *Hyopotamus* Owen in spite of statements to the contrary.

Our American species, distinct from European forms of this group, may be placed under the following genera: *Æpinacodon*, *Elomeryx*, *Heptacodon*, and *Octacodon*. The first of these is new and is made to include *A. deflectus* (Marsh), *A. americanus* (Leidy), and *A. rostratus* (Scott), species commonly classed under *Ancodus*.

One new subspecies is here described under the name *Elomeryx armatus angustus*, and the very complete skull is figured.

ART. XXII.—*Palæolagus, an Extinct Hare;* by EDWARD L. TROXELL.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

Among the many skeletons of the smaller mammals in the Yale Fossil Vertebrate Collection there are numerous specimens of the fossil rabbits and hares, some of which comprise unusually complete skulls, limbs, and vertebræ. Two distinct species of the genus *Palæolagus* Cope were secured by Professor Marsh in the early days of vertebrate exploration, one of them the smaller *P. haydeni,* which varies considerably in size and age characters and may be considered to include specimens of the subspecies *P. agapetillus,* very small, and of *P. intermedius,* moderately large. Distinct from it and widely separated is a larger species apparently closely allied to *P. turgidus.*

There is a most remarkable similarity between the Recent hares and rabbits, and their ancestors in the Oligocene. They evidently became adapted early to an

FIG. 1.—*Palæolagus haydeni.* Cat. No. 10356, Y. P. M. Side view of skull and jaws. Nat. size.

environment which, relative to its great diversity, has changed but little in the long lapse of time. Since their habitat and habits have been identified with swamps, plains, mountains—in fact, every conceivable condition—no barriers seem to check them; and because of their wide freedom and constant intermixing, they have changed but little since the time of *Palæolagus* in the Oligocene.

Generic characters.—As early as 1869 Joseph Leidy[1] drew attention to the distinction between the Recent and Oligocene forms as shown by the three and two lobes of

[1] J. Leidy, Journ. Acad. Nat. Sci. Phila. (2), 7, 331-334.

P_3. Cope,[2] Forsyth-Major,[3] Matthew,[4] and others have since pointed out additional differences: *Palæolagus* shows well developed postfrontal processes, the basicranial angle very small, the brain relatively small and flat, a less deep infolding of enamel on the internal side of the upper molars, and the presence of a crescentic lake. In all the Oligocene species the permanent lower teeth, when little worn, show a small third lobe arising on the posterior side of the second lobe near its summit; this, however, soon disappears. It is an interesting fact that the two lobes of the lower teeth are sometimes united only by cement, having no enamel connection whatever (fig. 20).

In the young, the anterior lobe of P_3 is a distinct, nearly isolated cone, but later the indentations, especially that

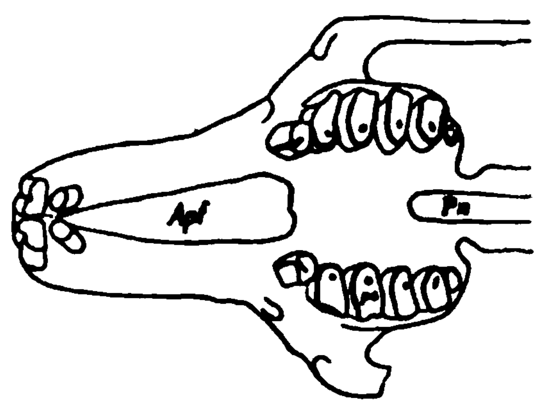

FIG. 2.—*Palæolagus haydeni.* Cat. No. 10304, Y. P. M. Palatal view of skull, to show small posterior nares, *Pn*, and anterior palatine foramina, *Apf*. Nat. size.

on the inner side, disappear, leaving the tooth as a single column with a shallow groove down the outer side. The anterior lobes take on two distinct types in the specimens at hand, i. e., that of a cylinder, round, or flattened and oval in cross-section.

Forsyth-Major has pointed out that the anterior teeth, both above and below, are more complicated than those posterior; this, he says, is due to the loss of the first and second molars of ancestral forms, thus throwing the additional burden on the anterior, terminal members of the series. It is characteristic of the genus *Palæolagus* that the posterior lobe of each lower tooth, after P_3, should be smaller than the anterior one.

Additional features.—In comparing the fossil and Recent skulls (see figs. 1-3) of the family Leporidæ in the Marsh Collection, the following points have been noted.

[2] E. D. Cope, Rept. U. S. Geol. Survey Terr., 3, 870, 888, 1884.
[3] C. J. Forsyth-Major, Trans. Linn. Soc. London (2), 7, 463-487, 1899.
[4] W. D. Matthew, Bull. Am. Mus. Nat. Hist., vol. 16, 306-308, 1902.

Palæolagus.	*Lepus.*
Palatine fissure opposite P^2.	Same position.
Palatine fissure very narrow.	Very wide.
Posterior nares very narrow.	Very wide.
Posterior nares opposite M^2.	Opposite P^4.
Palatal length ant.-post. 8 mm.	5 mm. on a much larger skull.
Upper tooth series with curved outer border due to small P^2 M^3.	Series with straight outer border.
P^2 narrow anterior and M^2 narrow posterior.	$P^{2,3}$ wide teeth, also M^2.
M_3 grooved on both sides.	M_3 grooved exterior.
Angle of ramus with narrow extension.	Angle very wide ant.-post.
Body of ramus deeper and wider.	Body of ramus slender.
Incisors begin under M_1 in thickened ramus.	Incisors begin anterior to P_3.
Diastema relatively short.	Diastema long.
Anterior to malar, no pit.	Malar with foramen.
On outer side, a fossa.	On outer side, sometimes a foramen.

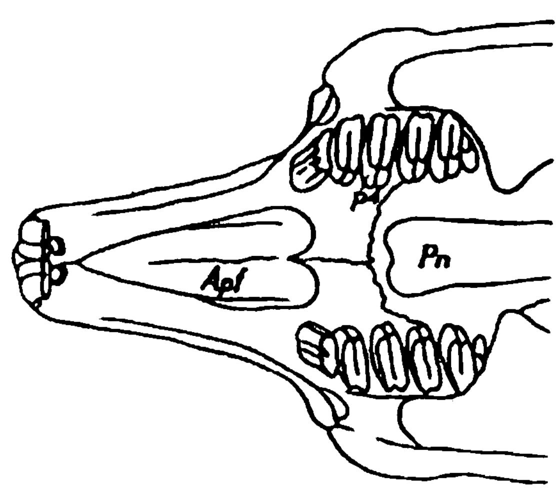

FIG. 3.—*Lepus*. Cat. No. 01370, Y. P. M. Diagram of palatal view of skull. Posterior nares, *Pn*; anterior palatine foramina, *Apf*. Nat. size.

Other seemingly important features which have come out in the course of this study are: the presence of a coronoid process on the jaw; the straight, much narrower ilium; the acetabular notch (which becomes a foramen in the hare); the thin, erect tubercle just in front of the acetabulum for the origin of the rectus femoris (later becomes flattened and oval in outline); the narrow head of the femur (contrasted to the broad one in *Lepus*, with the larger trochanters and the additional sharp edge extending distally), and the more prominent but more simple and restricted minor trochanter; all are to be seen in *Palæolagus*.

The fibula is fused to the shaft of the tibia in its distal half in a manner identical in both forms, showing the already progressive character in the Oligocene, or else the conservatism of the Recent, or both. The blade of the ilium is very straight and narrow in *Palæolagus*, especially at the sacral suture. The scar of this suture is V-shaped, and longer than wide. In the Recent form, this suture is U-shaped, wider than long, and beyond it there is a roughened area for tendinous attachment.

Concerning the loss of the coronoid[5] in later generations, it is apparent that along with the deepening of the jaw and the lengthening of the ramus, the temporal insertion on this process becomes weaker and weaker until now the anterior border of the ascending ramus, a double edge presenting a broad grooved surface, is reduced to a straight line. Furthermore, it is suggested that the lateral movement of the rabbit's jaw is brought about by

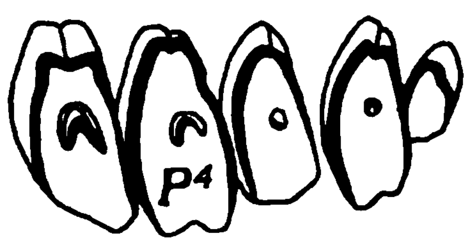

FIG. 4.—*Palæolagus turgidus.* Cat. No. 10306, Y. P. M. Crown view of upper molars and premolars, P^3 lost. $\times$ 2.

muscles attached to the angle and to places other than on the coronoid process, and that the broad incisors of the modern *Lepus* may also be correlated with an orthal movement of the jaws.

Matthew has pointed out that the head in *Palæolagus* is carried low, with the nose extended forward, as a result of the small basicranial angle; this is in contrast to *Lepus,* where the head is bent more strongly downward, showing, he says, an adaptation to a running habit. In harmony with this it is interesting to note that the large posterior nares of *Lepus* (fig. 3) and their position far forward, mentioned in the table of characters, are apparently a readjustment to facilitate breathing by shortening and enlarging the air passage. And so the whole structure of the Recent genus: the form of the femur, the

[5] The presence or absence of this process is not entirely uniform in the Recent hares. *L. americanus*, the so-called varying hare, has a very thin bone extending forward from the antero-external edge of the ascending ramus, which does not appear in certain rabbits. This may be a vestige of the coronoid process.

additional tubercles, the bending down of the face, and the nature of the air passage, all contribute to a cursorial adaptation.

Palæolagus turgidus Cope.

FIGS. 4-8.

The largest species of Oligocene rabbit is represented in the collection by several specimens consisting mostly of parts of mandibular rami. One specimen, the right maxillary (fig. 4), contains the complete tooth series save P^2. Except for the very large size, the most striking thing about this species is probably the great width of the

FIG. 5.

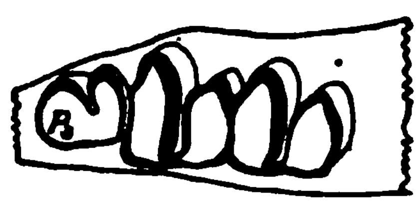

FIG. 6.

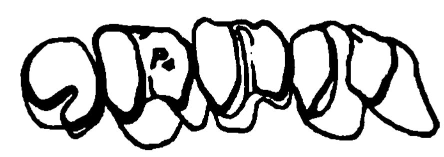

FIG. 5.—*Palæolagus turgidus.* Cat. No. 12069, Y. P. M. Crown view of lower teeth. $\times$ 2.

FIG. 6.—*Palæolagus turgidus.* Cat. No. 12068, Y. P. M. Crown view of lower teeth, M_3 lacking. $\times$ 2.

enamel bands, covering all sides of the upper molars but the outer ones. Compared to most specimens of *P. haydeni,* they are much wider relatively as well as actually.

In this particular specimen the enamel pattern is simple and it is evident that the teeth are much worn. They are short compared to what they must have been originally; the interior folds are entirely obliterated, and they have lost almost all trace of the crescents.

FIG. 7.

FIG. 8.

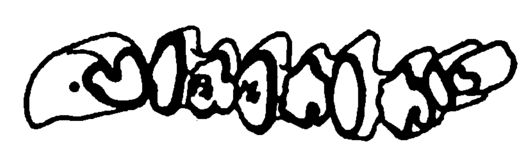

FIG. 7.—*Palæolagus* sp. ? cf. *P. turgidus.* Cat. No. 12073, Y. P. M. Crown view of lower molars of young individual. $\times$ 2.

FIG. 8.—*Palæolagus* sp. ? cf. *P. turgidus.* Cat. No. 12066, Y. P. M. Lower teeth of young individual. $\times$ 2.

In the mandible the enamel is continuous around the teeth, but in the late stages of wear it may disappear on the inner side. The incisor root has its beginning below M_1, as shown by the inflated region near the ventral border of the ramus.

The specimen shown in figure 5, a lower jaw, corre-

sponds most closely to the large maxillary just described; the large size of the three teeth remaining, $P_{3\cdot4}$ M_1, and the heavy bands of enamel appear to be typical of *P. turgidus.* Figure 6 shows a similar type of dentition, but of a smaller animal. In both of these, one sees the cylindrical form of P_3 with its smoothly infolded enamel and the lobes of the molariform teeth entirely separated except for a narrow bridge of enamel continuous with the inner border.

Two specimens, shown in figures 7 and 8, are of uncertain identification—may, in fact, represent a new species of rabbit—but because the evidence is not conclusive, and further because they are large, they are grouped with *P. turgidus.* The first, much younger and smaller, has a more complex folding of the enamel of P_3. Both show the more pointed, conical form of this tooth unworn, the intricate enamel foldings on the anterior side of the second lobe of M_1, the third small lobe posterior on the three intermediate teeth, and the apparent separation of their main lobes—all characters of youth.

This very large species exceeds in size the largest modern hare in the Museum Osteological Collection, one whose skull measures 91 mm. in length.

Palæolagus haydeni Cope.

Figs. 1, 2, 9-20.

Several views are here shown (figs. 9-16) illustrating the results of wear and also some slight individual variations, in different specimens of *P. haydeni* Cope. In this species the upper jaw has three deciduous premolars, in the lower there are two.

The first specimen (fig. 9) shows the deciduous teeth, three in number, slightly worn, standing alongside the true molars. Molar 1 is somewhat worn, but 2 and 3 are entirely untouched. The specimen shown in figure 10 has lost the milk teeth with the exception of a small fragment of Dp^1. P^2 is coming in beneath it. $P^{3\cdot4}$ are fully cut, but unworn. M^1 is well worn, M^2 not enough to obliterate the irregular outer enamel folds, M^3 is still unworn.

Specimen No. 10374 (fig. 11), partly due to wear, partly to individual variation, shows a greater complication of enamel. The technique of drawing the P^3 gives the outline of enamel areas rather than the full enamel band. The right maxillary (fig. 12) shows the first and last of the series of teeth but little worn; $P^{3\cdot4}$ $M^{1\cdot2}$ have worn to

the condition most commonly seen in the species. The next specimen shows the unique double loop on the internal fold of P^3 (fig. 13).

Figures 14 and 15 show about the same state of wear; the latter is the more advanced, for M^1 has lost the crescent and P^3 the antero-exterior fold which had been confluent with its crescent. In the specimen shown in figure 16, one should note the various results of wear: P^2 becomes much larger as the conical end disappears; P^3 is at its maximum width transverse; P^4 has lost its crescent; the inner fold of M^1 is isolated to form a long

FIG. 9—16.

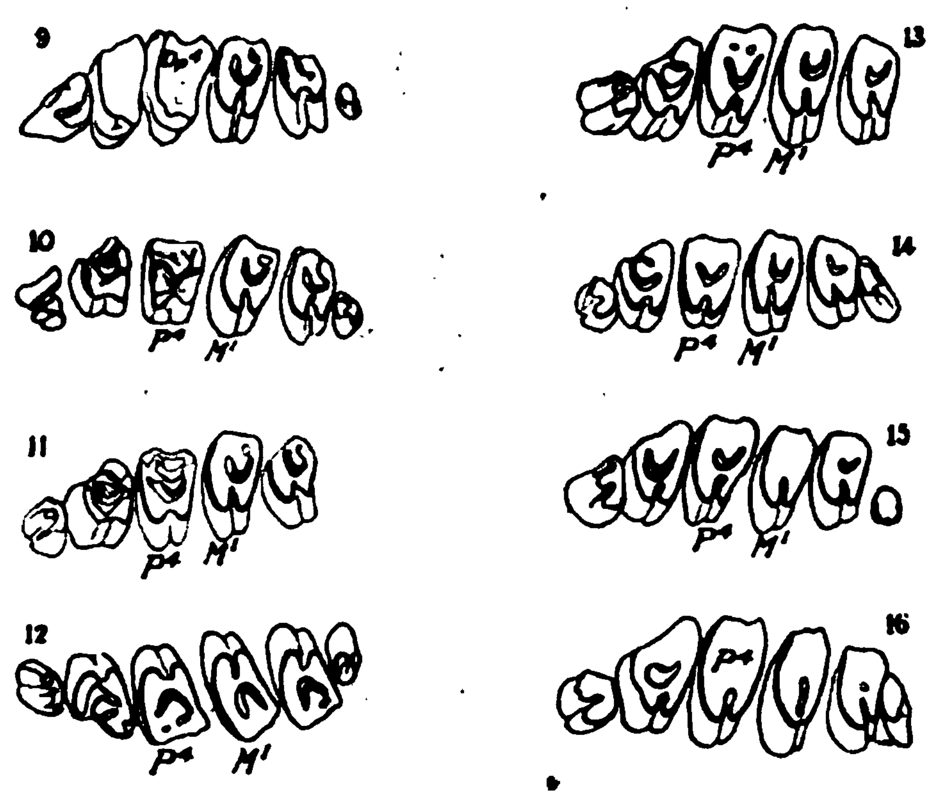

FIG. 9.—*Palæolagus haydeni.* Cat. No. 12080, Y. P. M. Upper milk and true molars. × 2.

FIG. 10.—*Palæolagus haydeni.* Cat. No. 12081, Y. P. M. Upper teeth of young individual. × 2.

FIG. 11.—*Palæolagus haydeni.* Cat. No. 10374, Y. P. M. Upper dentition (except M^3) of young individual. × 2.

FIG. 12.—*Palæolagus haydeni.* Cat. No. 10369, Y. P. M. Somewhat worn upper dentition. × 2.

FIGS. 13-16.—*Palæolagus haydeni,* Cat. Nos. 12082, 10377, 12084, and 12083, Y. P. M. To show successively advancing stages of wear and reduction of lakes of upper molars and premolars. × 2.

slender lake; M^2 shows the last sign of the crescent, while M^3 is reduced essentially to a simple cylinder.

Other stages might be illustrated to show the final elimination of all the foldings inside the outer boundary of the tooth.

In the following four views (figs. 17-20), of various subspecies of *P. haydeni,* three show the milk teeth beside the first true molar. In the first specimen (fig. 17) Dp_3 shows the prominent cusps and deep infoldings which are already much subdued in the next specimen (fig. 18);

the first milk tooth partakes of the character of the third lower premolar in *Lepus,* in having three lobes, but the marks of these lobes do not go beyond half the length of the short-crowned teeth. The second deciduous tooth of this specimen, also short-crowned, shows the distinct,

FIG. 17.

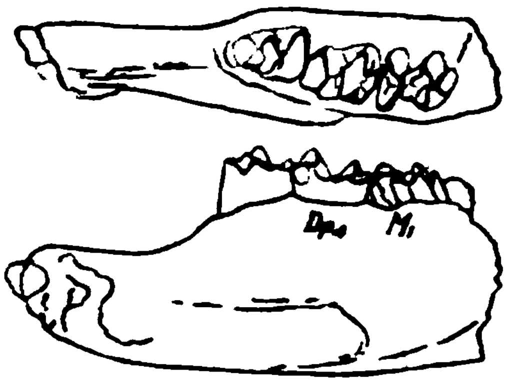

FIG. 18.

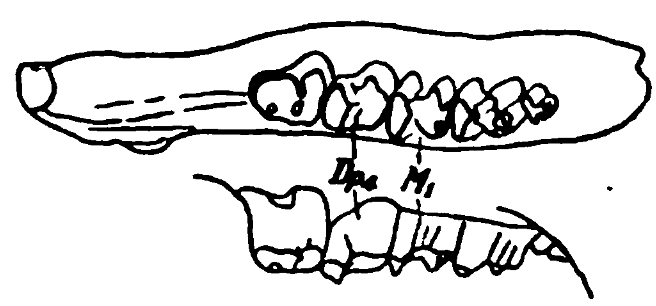

FIG. 17.—*Palæolagus haydeni agapetillus.* Cat. No. 12076, Y. P. M. Upper and side view of mandible, with deciduous premolars and first true molar. × 2.

FIG. 18.—*Palæolagus haydeni.* Cat. No. 12071, Y. P. M. Upper and outer side views of mandible, with two deciduous and three permanent teeth. × 2.

small, posterior lobe which is prophetic of the true molars. The interesting first molar will be discussed below.

Specimen No. 12071 (fig. 18) shows the first milk tooth with the most of the inner folds eliminated by wear. All track is lost of the posterior or third lobe in the second

FIG. 19.

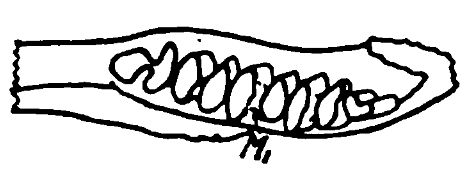

FIG. 20.

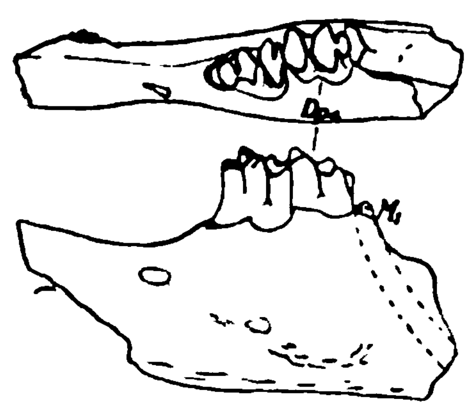

FIG. 19.—*Palæolagus haydeni agapetillus.* Cat. No. 12077, Y. P. M. Crown view of ramus of mandible. A very small subspecies. × 2.

FIG. 20.—*Palæolagus haydeni.* Cat. No. 12075, Y. P. M. Top and side views of lower jaw, showing deciduous premolars, $Dp_{3\cdot 4}$, and anterior half of first true molar, M_1. × 2.

milk tooth. Both $M_{1\cdot 2}$ have the small third lobes; this cusp in the unworn M_2 is separated from the larger lobe, but M_1 illustrates well how it becomes attached after only a little wear.

Another specimen (fig. 19) consists of the right ramus of a very small individual, probably the typical *P. agape-*

tillus. Note the very deep indentations in P_3, the wide separations of the lobes of each $P_4M_{1\cdot 2}$ and also the antero-posterior extension of M_3.

The very young individual illustrated in figure 20 not only shows the two milk teeth well preserved, but also the anterior half of the first molar pushing up just behind. This portion of molar in its unbroken enamel demonstrates the fact that the two parts of the tooth are simply cemented together, having no intimate connection.

Interpretation of milk dentition.—The question arises often as to what relation the milk teeth bear to the permanent teeth both (1) of the time, (2) of the descendants, and (3) of the ancestors. The three lobes of the first deciduous lower tooth seem to be prophetic of *Lepus*, the modern representative of the race; sometimes the second deciduous tooth shows the features of the tooth to follow in its place, having the small posterior cone in addition to the two main lobes; but sometimes the teeth are patterned in retrospect.

Probably the most interesting comparison may be made between M_1 of specimen No. 12076 (fig. 17), with its many cusps, and the permanent short-crowned molar of *Ictops*. The arrangement of the cusps of the talonid or posterior lobe, the transverse arrangement of the anterior half of the tooth, and the low area between the lobes, in *Palæolagus* having three tubercles, seem to link this specimen up with the insectivores. Of course the teeth of the latter are much more primitive in their brachyodonty, and they differ in having an additional cusp in front of the large double-cusped anterior lobe.

Summary.

It is difficult to draw the dividing line between the Oligocene species of *Palæolagus* except for *P. haydeni* and *P. turgidus*. *P. agapetillus* and *P. intermedius* are apparently distinguishable from *P. haydeni* on the basis of size alone, and are here considered as subspecies. Although there is a very great resemblance between the Oligocene forms and the Recent ones, yet there are striking differences, and most of those of the skeleton may be ascribed to a cursorial adaptation in the Recent form, *Lepus;* in this connection the position and size of the nares are of especial importance.

A number of views of the teeth are given to illustrate variations, mostly due to age, and to publish for the first time detailed drawings of the milk dentition.

ART. XXIII.—*White Mountain Physiography;* by ALFRED C. LANE.

Recent reprints by Goldthwait[1] and Lobeck[2], taken with me on a week's tramp from Lake Kezar over Baldface and through the Carter Notch to Mount Madison, thence along the Presidential Range to the Crawford Notch, thence by train to Lake Winnepesaukee, with a day or two there, added much to the pleasure of the trip, and made it of greater profit geologically than previous visits to the White Mountains. Coming home and comparing them with Barrell's recent papers as edited by Dr. H. H. Robinson,[3] his earlier papers,[4] Fairchild's work,[5] and the older work of Woodward,[6] Daly,[7] and Wright,[8] I have been led to certain thoughts that are perhaps worth brief record, even though I have no great critical disagreement, nor any mass of new fact to add. For even in the case of scientific testimony, it is well to have confirmation by the mouth of more than one witness.

Goldthwait seems to me without doubt right in his recognition of glacial cirques that antedate the culmination of the ice age, when the summit of Mount Washington was overridden. Not only are there the evidences of the glaciated rims of the cirques, as given by him, but it seems to me natural that the local glaciers which, working backward, carved these amphitheaters, should have been the forerunners of the great ice sheet. During a time of increasing glaciation in advance of the main sheet, actively eroding glaciers would naturally form around high peaks. Afterward, during the time of wasting away and recession, as in the recession of a river flood, deposition rather than erosion is the order of the day. As the climate grew milder and the ice front retreated from Long Island and Cape Cod, the ice level

[1] J. W. Goldthwait, this Journal (4), 35, 1-19, 1913, and 37, 451, 465, 1914; Bull. Geol. Soc. America, 27, 263-294, 1916; see also Ibid., 31, 112, 1920.

[2] A. K. Lobeck, Geog. Rev., Jan. 1917, 54-70.

[3] Joseph Barrell, this Journal (4), 49, especially pp. 407-428, 1920.

[4] Joseph Barell, Proc. and Coll., Wyoming Hist. and Geol. Soc., 12, 25-54, 1912; Bull. Geol. Soc. America, 24, 696, 1913, with the discussions by Johnson and Davis; this Journal (4), 40, 1, 1915.

[5] H. L. Fairchild, Bull. Geol. Soc. America, 29, 209, 1918.

[6] R. S. Woodward, U. S. Geol. Survey, Bull. 48, 1888.

[7] R. A. Daly, Jour. Geology, 13, 105, 1905.

[8] F. E. Wright, Bull. Geol. Soc. America, 21, 717-730, 1910.

must have gone down as well as back, and as the peaks of the White Mountains emerged as nunataks, the White Mountain massif must have been a pretty effective obstacle to vigorous advance. At the same time the disposal of a great ice sheet needs a milder climate than that in which one would just appear. Thus we should not then expect any local centers of glaciation, especially when, as we shall see, the mountains were nearly a thousand feet lower than at present.

If, then, we state the history of the accordant levels in the terms of Daly, the story would seem to run as follows:

Toward the close of the Paleozoic, the Appalachian revolution, beginning in the Pennsylvanian, produced great folding and an invasion of the Paleozoic sediments by granites until they were altered so as to be nearly as resistant to erosion as granites. Devonian black shales were converted into chiastolite schists such as we find on the Osgood trail of Mount Madison. Any accordant levels produced by the "limiting strength" and "isostatic adjustment" of this time were far above the present, not less than 2000 feet above the top of Mount Washington.

All the points "above the timber line," however, passed into a zone of relatively vigorous erosion, and may have been attacked by Permian glaciation. This attack would be especially strong on the unmetamorphosed rocks and there would be a tendency to wear down the ranges to a "rough accordance." When erosion reached the deeper metamorphosed layer, it would, as Daly says, go on more slowly. It seems to me that I saw such a disproportionate abundance of porphyritic marginal facies of granites, and of fibrolite, chiastolite, and tourmaline contact minerals, as to suggest that erosion had not gone far below the "level of metamorphism" which, as Daly points out (op. cit., p. 116), may be much less uneven than the folding surface.

I think there are still traces of the folds in the topography, of a synclinal from Littleton to Hanover, and a shallower one, higher up on the general bulge, from Goshen to Kearsarge, while the Presidential Range is the stump of an anticlinal, left probably not as the relic of an upfold, but as a more granitized and resistant core. The long ridges of Jura or Allegheny type are gone, and the very bottoms of the folds were higher than Mount Kearsarge. But it looks as though the top of the meta-

morphosed zone was not much higher. Thus, during the Mesozoic, when erosion went on with little local differential uplift or disturbance when the sea rose (Barrell says to 2450 feet A. T.), the Paleozoic White Mountains were reduced to ridges in hard rocks, well below timber line, in fact, not much over 4000 feet above the level of the Cretaceous sea. If we go back into the mountains and look, not for the heights of the old surface, but for the lower parts as near as possible to the old sea-level line, low gaps and necks not likely to have suffered much since, we find, besides some "shoulders" or "lawns" between 5000 and 4000 feet, of which I shall write later, many on Cutter's 1918 map of the Appalachian Mountain Club not far from 3000 feet. I had picked out Maple Mountains, 2635 feet A. T. (44° 10′ Lat., 71° 17′ Long.) as representing the lowland near Mount Washington, and was pleased to find that it checks quite well with Barrell's 2450-foot "Becket terrace" of the Cretaceous. A lot of points rise only a short distance above this one (Mitten, Pine Peak, and Mount Little Wildcat, Rockybranch Ridge Stairs, Crawford, Parker, Black, Saunders). It would not be hard to imagine lower levels, but the independent coincidence of my judgment with Barrell's figure gives me some confidence.

But how about the "lawns" and shoulders of the "Alpine garden" which Goldthwait takes to be remnants of an old grade? I should explain them thus. The Cretaceous 4000-foot ridges were not above timber line, but the elevations of the Tertiary carried them above timber line, and the parts projecting were subject to more rapid erosion. When they got high enough, and the climate rigorous enough, glaciers occupied the ravines and carved the cirques, while all during the times of elevation the rivers were busy cutting down to lower grades. I think cirques occur lower than Goldthwait is inclined to allow, for North and South Baldface and Eagle Crag seem to surround a well-marked cirque extending from 3000 to 2000 feet.

Finally, the advancing ice sheet swathed all the lower parts of the mountains in ice, and put a stop to the local carving, did some polishing, but little additional heavy cutting. It seems to me that the ice surface must have been for a long time at level; this "lawn," now between 4800 and 5500 feet, did not check the wasting by avalanche of the nunataks above, but started to produce that ac-

cordant level which F. E. Wright has emphasized in his Iceland studies, and to which Daly refers (op. cit., p. 119). This stage of the ice top must surely have occurred during the waxing and waning stages of the Wisconsin, but it is easy also to imagine that when the ice moved out in earlier parts of the ice age from the Keewatin and Patricia centers, it reached the White Mountains, but did not altogether bury them, especially if they stood higher.

De Geer finds a relatively long halt in the recession of the ice in Scandinavia, and the level of the ice cap top at such a time may be registered in the "lawn" level.

Thus, while it may be well to suspend judgment, as Goldthwait does, I am inclined to agree with Lobeck that these are not remnants of the "New England peneplane" but of an "accordant level" produced as described by Daly and Wright. There ought to be remnants of such a level. The "Felsenmeer" which Daly has emphasized as characteristic is well marked on all the peaks, and even the lower till is largely of angular blocks which I can easiest conceive of as the result of avalanches from nunataks on to the old ice surface, which have been allowed to settle gently without being compacted as the ice sheet wasted away.

Wright's study of the cycle of ice sheet erosion is well worthy of careful consideration.

But while I agree with Lobeck that the "New England peneplane," as commonly understood, "ends abruptly at the foot of the White Mountains," where its elevation is about 1000 feet A. T. and it shows even better in the field than in his photographs, I agree with Barrell that it is a plain of marine denudation. The notch in the hills is distinct and like a sea-cliff, and most so where they faced the broad Atlantic. I should interpret it as probably corresponding to Barrell's "Litchfield terrace" of the Pliocene, which on this projecting salient had cut so far back as in general to pass and obliterate the earlier and higher "Goshen" and "Cornwall" terraces, and in some places the higher "Canaan" and "Becket" terraces. In fact, the Tertiary elevations were slow enough or lasted long enough to pretty well dissect the 2600-foot peneplane, and so far as one can tell after the glacial filling that followed, to adjust the rivers at least to the 1000-foot level. Barrell has two or three terraces of Tertiary time below the Litchfield, but to find traces of

these, if they exist, is no matter of a week's glance, for they are obscured by the levels of glacial outwash deposition studied by Fairchild.

The series of late Tertiary and early Pleistocene elevations, coupled with climatic changes, brought on the ice age and the enswathement by an ice cap. The tendency of an ice cap 10,000 feet thick extending from Labrador, that is, with a radius of 9°, would be by gravity to draw the water to it, so that if stagnant and full of crevasses connecting with the sea, the sea-level would be 395 feet higher at the center, and 240 feet at the margin,[9] than were there no ice there. If we found no sea-level next the old ice front as high as this above the present sea-level, it might well be taken to indicate depression of the White Mountain region since the ice left it. On the other hand, if we suppose a certain amount of compression and isostatic adjustment of the crust under the ice load, and that readjustment took place as the ice melted, it is easy to account for any signs of depression and elevation of the sea-level up to one third of the thickness of the assumed ice sheet. If, then, we suppose an ice sheet up to the level of the Boott Spur, say 5300 feet 5% A. T., it would have a thickness above the present surface of some 2700 feet, and could account for a deep sea-level in its crevasses and in front of it some 900 feet above the present sea-level. This would be the lower limit of the earliest and widest post-glacial valley erosion, the limit up to which esker delta levels would build, and toward which valley train deposits should be abundant. It is, I think, the level followed by Fairchild, and given by him as 725 feet A. T. at Bartletts on the Saco River, 800 feet at Goshen on the Androscoggin. Barrell has two Pliocene terraces, the "Prospect" at 940 feet, and the "Towantic" at 740 feet, that may easily blend with it in broad landscape views, but should pass under the glacial deposits, not over, and would be likely to have a different tilt.

It must not be forgotten that here, as in Michigan, a plane connecting the various marine levels close to the ice front at different stages of the ice front by no means represents the water level at any one time. The disturbing effect of the ice on the water-level retired with the ice front, in part simultaneously, in part shortly after,

[9] Using Woodward's formula 64 and 67 of Bull. 48, with $\beta = 9°$.

so that lines of simultaneous water-level (niveau=equipotential lines) will feather out as they go north. If, however, the Boott Spur and the other "lawns" mark a period of relative permanence in the ice, a pause in retreat or re-advance, then the niveau line corresponding thereto might be extra well marked. The sea-level for the 725-foot terrace at Bartletts could not have been much below this datum, (for it is less than 20 miles of wide valley until it opens out on the old shore-line.) Thence the sea-level drawn toward the ice at the time sloped off a little, and if the sea-bottom rose rapidly as the pressure of the ice was removed, so that they had already begun to rise, then present traces of that level should slope even more away from the mountains. The sea-bottom terrace would slope still more. Thus, well developed post-glacial terraces should slope more than the earlier ones, to which Barrell gave a slope of 7 feet to the mile. Thus, the sea-bottom terrace corresponding to the Bartlett 725-foot level might well be under the 575-foot level, the 600 feet so prominent around Lake Winnepesaukee. But I did not try to disentangle the lower levels on which Goldthwait is now at work. When to the shifting volume of water in the ocean and the gravitative effect of the ice, which we know must have had an effect, is added the compressive effect of an ice sheet of which we do not know the thickness or the effect, only a very careful study of the results may perhaps give us a clue to the efficient causes. But it does seem worth mentioning that an ice sheet which was just thick enough by its swathing effect to produce the high-level "lawns" like Boott Spur, was probably also competent to produce just such a depression as we find indicated by the highest post-glacial sea-levels around the southeast flank of the mountains.

ART. XXIV.—*An Alkali Gneiss from the Pre-Cambrian of New Jersey;* by NORMAN E. A. HINDS.

Introduction.

The rarity of foliated alkali igneous rocks of primary origin is well known to petrographers. A few occurrences have been cited by Rosenbusch[1] and Washington's[2] latest compilation of rock analyses has added new types, but, as compared with the known volume of alkali igneous rocks, their metamorphic equivalents have been found on an extremely small scale. This paper adds a further example in the form of an alkali quartz-syenite gneiss from the pre-Cambrian complex of New Jersey. The rock was collected by Dr. J. E. Wolff from a tunnel cut through Van Nest Gap, near the town of Oxford Furnace, in the west central part of New Jersey, for the Delaware, Lackawanna, and Western Railroad.

The writer wishes to express his thanks to Dr. Wolff for many helpful suggestions in the preparation of this paper, and for the chemical analyses which he kindly made.

Geology.

According to Wolff and Brooks,[3] the pre-Cambrian series in New Jersey occupies a highland belt "about 20 miles wide, which runs across the State, and continues northeastward into New York and southwestward into Pennsylvania. With the exception of a few longitudinal valleys, in which the younger Paleozoic rocks occur, the

[1] Rosenbusch, H., Elemente der Gesteinslehre, 1910, p. 620.
[2] Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey, Prof. Paper 99, 1917.
[3] Wolff, J. E., and Brooks, A. H. The age of the Franklin white limestone of Sussex County, New Jersey, U. S. Geol. Survey, 18th Ann. Rept., Pt. II, p. 431, 1898.

whole area is occupied chiefly by gneisses, representing in general a few recurring lithological types."

The Pre-Cambrian of this region is composed of a series of metamorphosed sedimentary and igneous rocks, with certain additional elements of doubtful affiliations. The sedimentary foliates, of which the Franklin limestone is the most important, include coarsely crystalline limestone, marble, quartzite, conglomerate, breccia, slate, and schists and gneisses of various types. The orthogneisses are divisible into three groups, the Pochuck, the Losee, and the Byram. Associated with these rocks are many non-foliated granitic and pegmatitic intrusions.

The exact geological relations of the Van Nest Gap gneiss are unknown, but, as will be shown later, its chemical and lithological characters very closely resembles those of certain phases of the Byram gneiss, and, for this reason, the rock is tentatively assigned to that group.

Spencer[4] states that the Byram gneiss includes "several varieties of granitoid gneiss which are lithologically related by the presence of potash-bearing feldspars among their principal mineral components. As thus defined, the formation includes the "Hamburg", "Sand Pond", and "Edison" gneisses, which were separately mapped by Wolff in the Franklin Furnace district; the "Oxford type" of gneiss, described by Nason; and the gneissoid granite of Breakneck Mountain on the Hudson, described by Merrill."

The relations of the Byram gneiss to the other members of the Pre-Cambrian in this region are rather obscure. It is reasonably certain that the contacts with the Franklin limestone and with the Pochuck gneiss are intrusive; hence these two members are older than the Byram phase. The Losee and Byram gneisses appear to be "approximately contemporaneous."

Petrography.

Megascopic.—The Van Nest Gap gneiss is a rather coarse, even-grained rock of dark grayish-green color, and of fresh, unweathered appearance. It exhibits a roughly parallel linear structure, due to the partial segregation of the hornblende into pencil-like stringers. Sur-

[4] Spencer, A. C., et al., U. S. Geol. Survey Atlas, Franklin Furnace Folio 161, 1908.

faces of the rock at right angles to this structure are quite even-grained.

Of the visible minerals, feldspar and hornblende predominate, while quartz and magnetite appear very sparingly. The feldspar is grayish-green in color, and possesses good and rather highly lustrous cleavage faces. The hornblende occurs in grains of various sizes, with large individuals the more common. The hornblende pencils, mentioned above, constitute the most striking feature of the rock. The quartz is light gray and glassy. A few small grains of magnetite are visible. The light constituents make up about 80 per cent of the rock.

Microscopic.—Microscopic examination shows the gneiss to be composed of plagioclase, microcline-microperthite, hornblende, microcline, and quartz, named in the order of their importance; and very subordinate amounts of accessory magnetite, biotite, zircon, and apatite. Micaceous and chloritic decomposition products occur to a limited extent. The texture is hypidiomorphic, medium to coarse granular. Evidences of pressure are rare, though certain of the feldspars show slightly curved twinning lamellæ, and both the quartz and the feldspar exhibit faint strain shadows.

Feldspars.—Of the feldspars, plagioclase and microperthite each compose about one-third of the rock, while microcline is much less abundant. The feldspars are quite clear, except for small stringers of micaceous decomposition products which have developed along the cleavage cracks.

Plagioclase occurs in large anhedral grains. The maximum extinction angle perpendicular to M(010) is 9°, hence the mineral is an oligoclase having a composition between $Ab_{75}An_{25}$ and $Ab_{70}An_{30}$. Microperthite occurs in coarse, interrupted intergrowths of microcline and albite, which are present in about equal amounts. The microperthite individuals are much larger than those of any of the other constituents. Microcline is abundant in small areas. Much of it presents clear and distinctive cross-hatched twinning. Orthoclase is not present in the Van Nest Gap rock although it is commonly found in the Byram gneisses.

Hornblende.—This mineral is the most abundant dark constituent. The grains vary in size; the larger are irregular, while many of the smaller individuals show

well developed crystal outlines. The hornblende is imperfectly segregated into pencil-like areas, and hence is responsible for the gneissic structure of the rock. The grains in these segregation-areas have their long axes roughly parallel, although a rather wide diversity of direction exists.

The hornblende is generally fresh, except for the development of small amounts of greenish decomposition products along cleavage cracks. The sections are brownish-green, and are strongly pleochroic; Y = dark brownish-green to greenish-brown; X = light brownish-green; Z = deep yellowish-brown; and Z > Y > X; Y is nearly = Z. The pleochroism is similar to that of a section of barkevikite from the type locality in Norway. Sections near (010) give 12 c′ to Z.

An analysis of the mineral by Dr. J. E. Wolff is given below. Analyses of two other hornblendes, also by Dr. Wolff from the Byram gneiss of Hamburg Mountain and of Waywayanda Mountain, near the northern border of New Jersey, are included in the table. Analyses 2 and 3 are incomplete, but they will serve to show the similarity of the hornblendes in rather widely separated exposures of this group of rocks.

TABLE I.

	1	2	3
SiO_2	39.10	38.78	34.38
Al_2O_3	7.61	8.72	13.39
Fe_2O_3	5.72	0.22	1.16
FeO	25.49	28.08	26.72
MgO	3.23	0.58	3.30
CaO	8.99	9.98	9.26
Na_2O	1.53	....	1.51
K_2O	2.02	3.85	1.87
H_2O +	2.88	....	....
H_2O —	0.34	....	....
TiO_2	2.13	2.71	5.53
MnO	0.56	0.69	0.45
	....	....	....
	99.60	93.61	97.57
Sp. G.	3.440	3.436	3.434

1. Hornblende from alkali quartz-syenite gneiss. Van Nest Gap, N. J.
2. Hornblende from Byram gneiss. Hamburg Mountain, N. J.
3. Hornblende from Byram gneiss. Waywayanda Mountain, N. J.

The mineral is an iron-rich hornblende related to barkevikite, though it has a higher iron and a lower alkali content than does typical barkevikite.

Quartz.—Quartz occurs sparingly in grains of medium size.

Accessories.—The accessories, magnetite, biotite, zircon, and apatite, are very subordinate in amount. Magnetite is present in large, irregular grains. Biotite occurs in a few ragged individuals, commonly associated with the hornblende. In such cases, the longer axes of the biotite grains are parallel to those of the hornblende. The biotite is brown in color, and exhibits strong pleochroism from light yellow through brownish-yellow to deep reddish-brown. Zircon is represented by numerous, small, prismatic sections, frequently showing perfect pyramidal terminations. Many larger basal sections are also present. The apatite individuals are of medium size, and have rounded or elliptical outlines. Most of the apatite and zircon is found in the pencils of hornblende.

Chemical composition.

The analysis of the rock, which was made by Dr. Wolff, is given on page 363. The rock is an akerose of the rang monzonase, order germanare, with the following norm:

Quartz	5.94
Orthoclase	24.46
Albite	44.54
Anorthite	10.01
Zircon	0.37
Apatite	0.34
Ilmenite	1.22
Magnetite	2.78
Diopside	2.88
Hypersthene	5.95
	98.34

The mode of the rock, determined by the Rosiwal method, is given below. The calculation of the mode from the chemical analysis gave results which checked very closely with these figures. The rock may be classed as an alkali quartz-syenite gneiss.

Plagioclase	32.64
Microperthite	30.45
Microcline	19.25
Quartz	7.93
Hornblende	15.77
Biotite	0.74
Magnetite	2.15
Apatite	0.42
Zircon	0.58
	99.91

The position of the rock in the new quantitative mineralogical classification, proposed by Johannsen,[5] is in Class 2, Order 2, Family 9 (Granodiorite).

The specific gravity of the Van Nest Gap gneiss is 2.841. As calculated from the norm, according to the method recently suggested by Iddings,[6] the value is 2.803. The difference between the two results is due to the fact that the hornblende has a higher specific gravity than its two normative equivalents, diopside and hypersthene, which Iddings gives as 3.28 and 3.33, respectively.

Relations of the Van Nest Gap gneiss to the Byram gneiss.

Bayley[7] has described the Byram series as including a number of granitoid gneisses lithologically related by the presence of potash feldspar as one of the chief mineral components. This feldspar may be either orthoclase or microcline, the latter occurring to the exclusion of the former in the Van Nest Gap rock. The first main type of the Byram gneiss is a dark-gray, moderately coarse-grained rock, composed essentially of microperthite, microcline, orthoclase, quartz, hornblende, or a little pyroxene, magnetite, and occasionally biotite. Oligoclase is usually subordinate, but may equal the other feldspars, as in the case in hand. Fresh rock of the second principal variety is pink, light-gray or white in color, and differs from Type I in the presence of much more quartz and in the paucity of the dark constituents.

The following table shows the close mineralogical

[5] Johannsen, A., A quantitative mineralogical classification of igneous rocks, Jour. Geol., vol. 28, pp. 38-60, 158-177, 1920.

[6] Iddings, J. P., Relative densities of igenous rocks calculated from their norms, this Journal, vol. 49, pp. 363-366, 1920.

[7] Bayley, W. S., U. S. Geol. Survey Atlas, Passaic Folio 158, 1908.

relation between the Van Nest Gap rock (Column 1) and an average of four specimens of the dark-colored Byram gneiss (Column 2). Column 3 gives the average mineral composition of three varieties of the light-colored member of this series, in which the proportions of the component minerals are seen to be notably different. The only available chemical analysis of the Byram gneiss is of a light-colored variety. As contrasted with the composition of the Van Nest Gap rock, which is typical of the darker phase, the high percentage of silica and the lower iron content are the outstanding features.

TABLE II.

	1	2	3
Quartz	7.93	10.50	27.33
Orthoclase	....	1.25	0.66
Microcline	9.25	11.25	52.00
Microperthite	30.43	49.00	10.33
Oligoclase	32.64	16.25	10.33
Hornblende	15.77	8.50	0.50
Augite	....	0.50	....
Biotite	0.74	....	1.33
Accessories (magnetite, apatite, zircon, titanite)	3.15	2.75	2.83
	99.91	100.00	99.98

1. Alkali quartz-syenite gneiss. Van Nest Gap, N. J.
2 and 3. A. C. Spencer et al., U. S. Geol. Survey Atlas, Franklin Furnace folio, **161**, p. 5, 1908.

Origin of the Byram gneiss.

According to Bayley,[8] the Losee, Byram, and the greater portion of the Pochuck gneisses are considered to be slightly foliated igneous rocks which have been intruded into a preexisting and now highly foliated pre-Cambrian sedimentary terrane. "The linear structure of the gneisses is regarded as the direct result of flowage of the viscous magma and of the crystallization of some of the minerals of the rocks under the influence of strains produced by flowage." The gneissoid structure is not due to later metamorphic effects which the region has undergone during the progress of various orogenic movements.

[8] Bayley, W. S., Iron mines and mining in New Jersey; New Jersey Geol. Survey, vol. VII, p. 126, 1910.

General relations.

The rarity of the primary alkaline orthogneisses has been alluded to briefly in an earlier part of this paper. Rosenbusch[9] says that rocks of this type in the form of quartz-bearing arfvedsonite gneisses were first recorded in the vicinity of Cervadaes, 8 kilometers north of Campo Major, in the province of Alemtejo, Portugal. This region has also yielded other varieties, including a quartz-poor arfvedsonite gneiss and a nepheline-aegirine gneiss. An alkaline gneiss, similar to the first-mentioned rock from Cervadaes except that riebeckite and aegirine replace arfvedsonite, has been recorded from Old Pedroso, 51.5 kilometers to the northeast of the above locality. Rosenbusch also cites arfvedsonite gneisses from near Vigo, Spain, and from near Baependy in the State of Minas Graes, Brazil; an alkaline gneiss with riebeckite and aegirine from near Gloggnitz, Austria; and an umptekite gneiss (astochite gneiss) from West Greenland. Cushing[10] has described an augite syenite gneiss from Loon Lake, New York, which is rich in the alkalies, due apparently to the abundance of orthoclase and albite. This rock closely resembles certain of the alkali syenites from Mt. Ascutney. The recent compilation of rock analyses by Washington[11] has added still other types,—a canadite gneiss from Sweden (Quensel); a nepheline syenite gneiss from Madagascar (Lacroix); two gneissoid alkali syenites from Gellivare, Sweden (Högbom); and an aegirite-riebeckite gneiss from Ross-shire, Scotland (Flett). The Van Nest Gap rock adds another example to this meager list.

From his discussion of these rocks, Rosenbusch[12] concludes (translated) that "alkali granites, alkali syenites, and nepheline syenites are known in the form of crystalline schists in the basement complex, and it may be expected that further investigations will bring to light monzonitic and essexitic types." From this summary it is evident that the foliated equivalents of the alkaline igneous rocks are decidedly unusual types, especially

[9] Rosenbusch, H., Elemente der Gesteinslehre, 1910, p. 620.
[10] Cushing, H. P.; Augite-syenite gneiss from near Loon Lake, New York, Bull. Geol. Soc. America, vol. 10, pp. 177-192, 1899.
[11] Washington, H. S.; Chemical analyses of Igneous Rocks, U. S. Geol. Survey, Prof. Paper 99, 1917.
[12] Op. cit., p. 622.

when the widespread occurrence of the alkaline rocks is considered.

Table III gives the analyses of a number of these alkaline orthogneisses. The examples cited belong to the alkali granites, the alkali syenites, and the nepheline syenites, the last named being the most numerous. The Van Nest Gap rock belongs to the alkali syenites.

TABLE III.

	1	2	3	4	5	6	7	8
SiO_2	61.18	65.88	59.52	75.90	63.26	56.44	55.99	63.45
Al_2O_3	16.86	16.03	21.24	11.89	14.84	20.52	20.18	18.31
Fe_2O_3	1.95	2.56	2.71	2.68	2.39	2.72	4.19	0.42
FeO	4.74	1.84	0.48	1.59	1.54	4.51	3.25	3.56
MgO	0.60	0.29	0.12	0.42	4.22	0.28	0.33	0.35
CaO	2.91	0.25	0.48	0.20	1.61	1.23	2.29	2.93
Na_2O	5.33	7.44	10.72	4.68	9.32	9.01	6.89	5.06
K_2O	4.12	4.66	3.92	3.83	0.70	4.80	5.59	5.15
H_2O+	0.85	0.34	0.50	tr	1.66	0.75	0.43	....
H_2O-	0.04	0.02	....	tr	....	0.12	....	....
TiO_2	0.61	tr	tr	tr	tr	0.12	....	0.07
MnO	0.06	....	tr	tr	tr	0.06	....	....
P_2O_5	0.15	....	....	....	....	....	....	....
CO_2	....	....	0.21	....	....	....	....	....
ZrO_2	0.16	0.45	....	....	....	....	....	....
	99.56	99.76	99.90	101.19	99.54	100.66	99.84	99.73

1. Alkali quartz-syenite gneiss (akerose). Van Nest Gap, N. Y. Dr. J. E. Wolff, analyst.
2. Arfvedsonite gneiss, Cervadaes, Alemtejo, Portugal. H. Rosenbusch, Elemente der Gesteinslehre, p. 620.
3. Aegirine-nepheline gneiss. From near locality "2". Ibid.
4. Riebeckite gneiss. Near Gloggnitz Austria. Ibid.
5. Umptekite gneiss (astochite gneiss). West Greenland, Ibid.
6. Canadite gneiss (miaskose). Lille Elringe, Almunge, Sweden. P. Quensel, Bull. Geol. Inst. Upsala, vol. 12, p. 190, 1914.
7. Nepheline-syenite gneiss (viezzenose). Makarainga, Madagascar. A. Lacroix, Comptes Rendus, vol. 155, p. 1125, 1913.
8. Augite-syenite gneiss (akerite). Loon Lake, N. Y. H. P. Cushing, Bull. Geol. Soc. America, vol. 10, 179-192, 1899.

Summary.

1. An alkaline gneiss from the pre-Cambrian of New Jersey is described with regard to its megascopic and microscopic characters.

2. Chemical analysis shows this rock to be an alkaline quartz syenite gneiss belonging to the subrang akerose, in the norm classification, and to the family granodiorite, in the quantitative mineralogical classification of Johannsen.

3. While the exact geological relations of the Van Nest Gap rock are unknown, its chemical composition place it with the dark colored variety of the Byram member of the New Jersey pre-Cambrian gneisses.

4. The Byram gneiss is considered to be an igneous rock in which foliation developed in the magma during the process of crystallization.

5. Alkaline gneisses from other localities are cited, and the scarcity of this type of foliates is emphasized.

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SCIENTIFIC INTELLIGENCE

I. Chemistry and Physics.

1. *The Double Decomposition of Salts in Connection with the Phase Rule.*—Two or three years ago it was announced by Etienne Rengade that in accordance with the phase rule a small quantity of water acting upon an excess of two salts with four different radicals or ions would necessarily cause the appearance in the solid condition of a third salt, one of the two other possible combinations of the ions. In contradiction to this statement Ravenau has recently stated that a mixture of $NaNO_3$ and NH_4Cl could exist without decomposition in the presence of a small quantity of water. Rengade has now shown, however, that this statement is incorrect, for he has found, both by microscopic examination and by analysis of the products of the treatment, that crystals of NaCl are formed in this case. He has found that NH_4NO_3 and NaCl give NH_4Cl as the third solid product, so that there are at ordinary temperature two ternary mixtures containing these four ions:

$$NaNO_3 + NH_4Cl + NaCl$$

and

$$NH_4NO_3 + NaCl + NH_4Cl.$$

He states that these can exist without change in contact with a small quantity of water, and that every other mixture of two, three or four of the salts containing the four ions will decompose, giving, according to their proportions, one or the other of the triple mixtures.

Rengade admits, however, that it is possible for two salts with different ions to remain in equilibrium without the formation of a third salt in the solid state. This is the case when the two salts are considerably less soluble than those formed by double decomposition. Consequently it is to be observed that his original

statement is incorrect, but he maintains that the exceptions to it are fully in accord with the phase rule.—*Comptes Rendus*, **172**, 60. H. L. W.

2. *A Comparison of the Atomic Weights of Terrestrial and Meteoric Nickel.*—About ten years ago it was shown by Baxter and Thorwaldsen that the atomic weight of meteoric iron is identical with that of terrestrial iron within the limits of experimental error. In view of the recent interest in isotopic elements, such as ordinary lead and the kinds of lead produced by radioaction transformations, G. P. BAXTER and L. W. PARSONS have compared the atomic weights of terrestrial and meteoric nickel. They have very carefully prepared nickel oxide, NiO, from the two sources, the meteoric nickel having been obtained wholly from the Cumpas meteorite found in 1903 near Cumpas, Senora, Mexico. They analyzed the samples of oxide by reduction when heated in hydrogen, and having made corrections for the minute amounts of occluded nitrogen and oxygen contained in the products, they found as averages 58.70 for the atomic weight of the terrestrial nickel and 58.68 for that of the meteoric nickel, where the difference is within the limits of experimental error. There is no evidence from these results, therefore, that there is any isotopic difference between the two kinds of nickel.—*Jour. Amer. Chem. Soc.*, **43**, 507. H. L. W.

3. *General and Industrial Organic Chemistry;* by ETTORE MOLINARI. Translated from the Third Enlarged and Revised Italian Edition by THOMAS H. POPE. Part I. Large 8vo, pp. 456. Philadelphia, 1921 (P. Blakiston's Son & Co. Price $8.00 net).—Two English editions of the inorganic part of this treatise have already received very favorable comment in this department of the Journal, and it is evident that the excellent and unusual features of that portion of the work are well shown in the volume under consideration. The author has aimed to bring about a reform in chemical instruction by strongly emphasizing the practical applications of the science in connection with the study of the theory. It appears that the plan offers great advantages in arousing the interest of the student and in training him well for a career in industrial work. Aside from its use as a text book, the work is a valuable one for reading and reference in connection with industrial processes and statistics of costs and production.

This first section of the organic part of the work deals chiefly with the aliphatic compounds, but it does not include the carbohydrates, nor does it describe the soap-making industry. Among the industries rather extensively treated here are those of petroleum, illuminating gas, explosives, and alcohol together with alcoholic beverages. The last subject is extensively treated, but there is a long foot-note giving strong arguments in favor of alcoholic abstinence. H. L. W.

4. *A Treatise on Chemistry*, by ROSCOE and SCHORLEMMER. Vol. I, The Non-Metallic Elements. 8vo, pp. 968. Fifth Edi-

tion, Completely Revised, by J. C. CAIN. London, 1920 (Macmillan and Co., Limited).—It is a pleasure to welcome a new edition of this important work which has served many of our older chemists since their younger days as a valuable source of reading and reference, for the first edition appeared in 1877. The beautiful portrait of John Dalton, the frontispiece, as well as many other illustrations are very familiar, having been retained in all the editions; but while the present editor, as he says, has "reverently preserved the general character and style of the book," it appears to have been very well brought to the present time. There have been many additions to our knowledge of the non-metallic elements and a gain of 199 pages in the size of the book since the time of the first appearance of this volume, but it is found that the present edition is only thirteen pages larger than the last one of 1911. The book is so well known that further comments upon its character and excellence seem to be unnecessary. H. L. W.

5. *Musical Sands.*—CECIL CARUS-WILSON has been interested in musical sands for a long time and has published several communications on the subject. He distinguishes two types of these sands according to the place of their occurrence: 1°, Desert sands such as are found at Jebel Nagous in the desert of Mt. Sinai and 2° Beach sand, of which the earliest recorded example was found on the Island of Eigg. The phenomenon reported in the first kind is as follows: When a disturbance was started in the upper layers on a slope the loose sand thus set in motion rolled down in widening lines like the spread of ripples from a disturbance on the surface of water. This was accompanied by a fluctuating musical sound described as partaking of the character of the note of a mellow church bell and sometimes it was like that of a stringed instrument.

The beach sands on the other hand are said to emit a staccato note under a footfall or when struck with a plunger of wood or brass. The author thinks that these notes are produced by the intermittent slipping and rubbing between clean and well rounded grains of quartz of nearly uniform size, free from roughness, sharp angularities, or adherent matter; apparently having in mind the stuttering motion of slate pencil upon a school slate, or the similar effect in the case of the wetted finger when rubbed on the edge of a tumbler. The vibrations thus started in the sand, or in the striking body, are ultimately elevated into a musical note. In support of this view Mr. Wilson has shown that the highly musical Eigg sand may be rendered mute by adding a certain quantity of dust or angular grains, and on the contrary, certain sands which were not previously musical may be made to emit notes after eliminating dust or angular grains.

The author's experiments were made only on beach sands and consisted chiefly in striking a sample of sand contained in a receptacle such as a porcelain cup which was found to be most suitable. The musical sound emitted depended upon the nature

and the size of the striking body or plunger, which would indicate that the latter acted as a resonator in compressural vibration, taking up the vibrations started by the rubbing grains. In cups of other materials, such as a paste-board box, a flower pot, or a rubber vessel, the sand was mute. Although this point was not mentioned it might be surmised that the porcelain was most suitable because its glazed surface more nearly approximated that of quartz than the other surfaces.

The author has no theory to offer in explanation of the origin of the note in the motion of desert sands and it is difficult to see how the granules should possess a period of vibration slow enough to account for the pitch of the sound observed.

A possible explanation may be found in the idea suggested by Osborne Reynolds (*Phil. Mag.* **20**, 469, 1885) that a mass of grains in coming to rest will take up an arrangement of minimum volume. When, however, they are disturbed the group may pass through many successive minima of volume and if these minima occur at approximately constant intervals of time the accompanying change of volume might conceivably transmit a periodic compression to the surrounding air and thus produce a musical sound.—*Discovery* **5**, 156, 1920.

6. *The Electric Furnace;* by HENRI MOISSAN. Pp. xvi, 313. Easton, Pa., 1920 (The Chemical Publishing Co.).—This is a second edition of the translation of the author's *Le Four Electrique,* Paris, 1897, the first edition having appeared in 1904. No attempt has been made to add in any way to the text of the original French edition. The work is divided into four rather long chapters which deal respectively with the description of Different Models of Furnaces, the Various Modifications of Carbon, the preparation of ten Elements in the Electric Furnace such as chromium, manganese, tungsten, vanadium, silicon, aluminum, etc., and finally with the preparation of Carbides, Silicides, Borides, Phosphides, Arsenides, and Sulphides.

The work of Moissan is too well known to call for any review. It is the purpose of the publishers to make these classic researches available for all who may wish them. The illustrations of the French text have been reproduced in a manner which may be sufficient for the purpose but nevertheless with the loss of all the artistic value of the originals.

7. *Lessons in Heat;* by WILLIAM S. FRANKLIN and BARRY MACNUTT. Pp. xi, 147. Bethlehem, Pa., 1920 (Franklin and Charles).—This is the third volume of the authors' Lesson Series. The philosophical ideas which underlie the Theory of Heat, such as temperature, quantity of heat, and entropy, are admittedly difficult to grasp and to formulate. The authors' main effort has been to connect up actual things and conditions with the mathematical symbols and this attempt to state the physical essence of thermodynamic principles has been commendably successful. The six chapters take up in succession Thermometry, Calorimetry, Changes of State, Heat Transfer, Properties of Gases and the

Thermodynamic Laws. While the book is free of the engineering slant of the preceding volume on Electricity it lays an excellent foundation for Heat Engineering. F. E. B.

8. *Matter and Motion;* by J. CLERK MAXWELL. Pp. x, 163. London, 1920 (Society for Promoting Christian Knowledge).—The present interest in the foundations of Mechanics makes this an opportune time for a new printing of Maxwell's well known little treatise on the principles of dynamics. It is edited by Sir Joseph Larmor who has added notes, a chapter on the Equations of Mition of a Connected System from the author's *Electricity and Magnetism,* and two appendices. The first of these treats of the Relativity of the Forces of Nature. The editor's discussion of the Einstein theory is given from a refreshingly detached point of view compared to the dogmatism of its avowed protagonists.

The second appendix develops the wider aspects of the Principle of Least Action. The book is further enriched by the reproduction of a hitherto unpublished portrait of Maxwell.

F. E. B.

9. *Mechanical Sciences Tripos;* Pp. 57. Cambridge, 1920 (Cambridge University Press).—A pamphlet containing reprints of the papers set in Applied Mechanics, Heat and Heat Engines, Theory of Structures, and Electricity, during the years 1912, 1913, 1914, 1915, and 1919. They contain a mine of suggestions for teachers who may desire to test the proficiency of honor students. F. E. B.

10. *A Text Book of Physics;* by W. WATSON. Pp. xxvi, 976. London, 1920 (Longmans, Green & Co.).—Extended treatises on Physics in English such as are available in German or in French do not exist, but that there is a considerable demand for a full one volume text is evidenced by the issue of a seventh edition of Watson's Physics. Notices of the second and the fifth editions have already appeared in this Journal (see **9**, 296, 1900 and **35**, 104, 1913).

After the death of the author in war service, the revision was entrusted to H. Moss, lecturer in Physics at The Imperial College of Science and Technology of London, who has corrected the values of the more important physical constants, and supplied material for some of the lacunae which existed in the earlier editions.

The new matter amounts to twenty-three pages distributed over thirty or more topics, among which may be noted: the McCleod gauge, Moduli of Elasticity, Callendar's constant pressure air thermometer and the constant flow calorimeter, sound ranging, the interferometer, the echelon grating, Gauss's theorem, Kirchhoff's laws, the d'Arsonval galvanometer, parallel connection of condensers, A. C. equations, and reflections of X-rays.

A conspicuous omission is any reference to crystal detectors, or to the thermionic vacuum tube. Possibly room should also have been found for the resolving power of a prism. The book

as a whole is to be commended as one which not only the student but any reader would be glad to possess. F. E. B.

II. Geology.

1. *The Crinoidea Flexibilia;* by Frank Springer. Smithsonian Institution Pub. No. 2501, two vols., text and plates, 486 pp., 79 pls., 51 text figs., 1920.—In these two grand volumes we have the results of a long labor of love by an able lawyer, a work made possible largely through his own financial resources and paleontologic ability, though he works at Washington in a most stimulating environment and in an institution that will always fully appreciate the gift of his great collections. The printing and paper of the monograph are of the best and the heliotype plates well reproduce the very beautiful and accurate drawings of Mr. Georg Liljevall, of Stockholm, and Mr. K. M. Chapman, of Sante Fe.

Wherever crinoids occur, there the author, or others for him, have gone and labored long to get these usually rare fossils. These co-workers he loves as much as his adopted children, the Echinoderma, and on pages 8 to 15 and in places throughout the text he writes feelingly and interestingly of their help and talent. The volumes are dedicated to the man who started him on his career in paleontology, Charles Wachsmuth, "collaborator and friend of early years."

It is interesting to note that the Silurian of Decatur County, western Tennessee, has yielded as great a variety of crinoids as that of the Swedish island of Gotland, and that they exhibit "in some respects a remarkable parallelism with the Gotland fauna," while the Laurel limestone of Indiana bears a similar striking resemblance (p. 15). Both American areas got their faunas through what is now the Gulf of Mexico embayment.

While the author's method of study is in the main morphologic, yet the fossil forms are also studied in the light of the recent crinoids. He tells us that of living forms there are now described 567, with about 50 new ones to be defined, and that the U. S. National Museum has no fewer than about 350 species represented by 5,387 specimens. This great collection of recent crinoids has been built up largely by Doctor Austin H. Clark, with the backing of Mr. Springer. Close attention is also given to the ontogenetic stages in living genera, and many of these stages (in 5 genera) are figured from drawings by H. E. Wilson on the three first plates. In *Comactinia meridionalis* from off Yucatan there is retained a longer series of development stages than is commonly present, and the study of this species leads the author to conclude that there is "in the ontogeny of this living crinoid an unusually close recapitulation of the phylogenetic history of some of the Paleozoic groups of the class" (86). The Taxocrinidae "represent the true Flexibilia type," and are "comparable to stages in the ontogeny of living crinoids" (96).

On pages 402-403 is described a remarkable case of "recuperation," where a specimen of *Taxocrinus colletti* regenerated an entire crown from the infrabasals and one basal, indicating that "the seat of vitality was lodged low down within the infrabasals."

For twenty years, Springer has been gathering Crinoidea Flexibilia and now he presents all the morphologic and geologic detail of the 176 known species (54 new) in 31 genera (4 are new, but Springer is the author of 13). Of these, 109 are American, the remainder European. They begin in the Ordovician with 2 forms, differentiate quickly in the Silurian, where 71 are known, 34 occur in the Devonian, 68 in the Mississippian, and the order dies out in the early Pennsylvanian, where but a single species is known. Besides, the author treats in the same detail 6 other genera (Incertae sedis) that have been referred on insufficient grounds to the Flexibilia, one of which is the curious *Edriocrinus* with 9 species (4 new) that are attached by the calyx to foreign objects, in this suggesting the recent *Holopus*.

The author's principle of classification is morphologic and not phylogenetic, and the order Flexibilia is said to be "an offshoot from the dicyclic Inadunata. . . through the non-pinnulate Dendrocrinidae" (88). This took place early in the middle Ordovician, in fact, it was at this time that most of the ordinal differentiation of the crinoids from the cystids occurred. Springer says:

"Thus it seems that at this very early stage in the geological scale we have forms exhibiting variously intermingled characters of the larger divisions of the crinoids, with some of the essential cystid structure more or less impressed upon one of them; and that these represent relatively recent departures from the common ancestral type, tending in different degrees toward the lines of evolution which produced the several orders of the crinoids. In *Protaxocrinus* the Flexible characters were already well established; in *Cupullocrinus* and *Reteocrinus* the tendency was toward the Inadunata and Camerata respectively, while still complicated by other characters; while in *Cleiocrinus* the strong survival of cystid characters prevented the establishment of a distinct evolutionary line in either of the crinoidal orders" (91).

Springer maintains that with our present knowledge crinoids are best classified into four orders, as follows: (1) Inadunata, having generalized forms ranging from the Ordovician to Recent; (2) Flexibilia, having more or less specialized Paleozoic genera; (3) Camerata, with highly specialized forms; and (4) Articulata, the latest derived crinoids, beginning in the Jurassic and extending into Recent times.

We congratulate Doctor Springer on the completion of this monumental work, one of the best paleontologic monographs yet published in America, and we look forward with much expectation to the several other works he announces. C. S.

2. *The Dunkard Series of Ohio;* by C. R. Stauffer and C. R. Schroyer. Geol. Survey Ohio, 4th ser., Bull. **22**, 167 pp., 13 pls., 1 map, 1920.—In this very detailed account of the stratigraphy of

the terminal deposits of the Paleozoic of Ohio, the Upper Barren of the older reports, known since 1891 as the Dunkard series, is placed at the bottom of the Permian system, in conformity with general usage. There is no general break between the Pennsylvanian and Permian. The series has a distribution in Pennsylvania, West Virginia, and Ohio of about 8,000 square miles; in the last-named state it is now known to cover about 1,213 square miles to the north and west of the Ohio River from Wheeling to Pomeroy. The thickness in Ohio is about 600 feet, in Pennsylvania from 900 to 1,000 feet, but originally the Dunkard must have been considerably thicker. It consists in the main of sandy shales, interspersed with more or less persistent sandstones (about 9, having variable thicknesses that at times attain to about 35 feet), with impure limestones (5, usually thin but locally up to 16 feet thick), and with thin coals (6, only one thick enough to mine, but that one 5 to 7 feet thick in places). In this way the series is divided into 22 named zones.

In Ohio, the sandstones of the Dunkard are sometimes conglomeratic and sun-cracked, more often the quartz is sharp in grain, cross-bedded, rippled, and nearly always micaceous; in Pennsylvania, they are more or less feldspathic. The shales are red in the upper part and in places the whole series is of the same color; locally occur selenite crystals or traces of gypsum. The limestones are more or less muddy and probably all of fresh-water origin, since the only unmistakable marine fossil is *Lingula permiana,* n. sp., a small form restricted to a black shale associated with one of the coal beds. Even though all the invertebrates are described as new species, and most of them referred to marine genera, they are thought to be probably forms living in fresh water or on the land. All are small, and most of them exceedingly so. They include 4 bivalves, 3 gastropods, *Spirorbis,* and ostracods. In addition, there are fish scales and ganoid teeth, at least one large dorsal shark spine, the dorsal spine of a reptile (*Edaphosaurus*), and coprolites. At the base of the Dunkard occurs the Cassville shale, which in West Virginia has yielded a Permian flora of 107 species, and a number of cockroach wings; in Ohio, however, only 21 plant species have been noted.

The reviewer gets the impression from the book that the climate of Dunkard time was still warm, though tending to become more and more arid, that the gradually subsiding coastal swamp area of the Dunkard lay near sea-level, and that but rarely did the sea back water far into the region of this earliest of Permian depositions. The report is especially valuable for any one who wishes to dig out the environmental conditions of the time through the detailed presentation of the many local exposures. C. S.

3. *The Stratigraphy and Paleontology of Toronto and Vicinity, Part I, The Pelecypoda;* by BEATRICE HELEN STEWART. Twenty-ninth Ann. Rept., Ontario Dept. Mines, pp. 1-59, 5 pls., 1920.—It is interesting to note the revival of interest in the local paleontology of the strata about Toronto. It is proposed first to

describe the later Ordovician faunas and then modernize the correlation in accordance with the sequences elsewhere. In Part I are described 59 species of bivalves, of which 53 are specifically determined, and 11 are new. C. S.

4. *Notes on the Geology and Oil Possibilities of the northern Diablo Plateau in Texas;* by J. W. BEEDE. Univ. of Texas Bull. No. 1852, 40 pp., 7 pls. (1 geol. map), 2 text figs., 1918 (1920).—This report is valuable not only for what it describes, as indicated in the title, but for the discovery it records of a Chester fauna (the Helms group of strata, 400-600 feet thick) beneath the Pennsylvanian-Permian. There is also a very valuable correlation table synchronizing the various areas of the late Paleozoic formations of Texas with those of Oklahoma and Kansas. The stratigraphy of Texas is advancing with leaps and bounds, and the State Survey is to be congratulated on the rapid progress made. C. S.

5. *The Weno and Pawpaw Formations of the Texas Comanchean;* by W. S. ADKINS, and *On a new Ammonite Fauna of the Lower Turonian of Mexico;* by EMIL BÖSE. Univ. of Texas Bull. No. 1856, 257 pp. (quarto), 20 pls., 20 text figs., 1918 (1920).—In the first part of this memoir are described the two formations named in the title, and their distribution is traced throughout the state. Their faunas consist of 69 forms, of which 51 are named specifically. Of new species there are 29. Of ammonites there are more forms than is usual in the Lower Cretaceous of America. The second part of the memoir describes an interesting but small assemblage of invertebrates, chiefly ammonites, that occurs near the base of the American Upper Cretaceous in northern Mexico. Of species studied there are 21, but only 8 are specifically determined, 7 of these being new. The affinities of these forms are clearly with those of the Mediterranean Turonian. C. S.

6. *Fossil Corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent Coral Reefs;* by THOMAS WAYLAND VAUGHAN. U. S. Nat. Mus., Bull. **103**, pp. 189-524, pls. 68-152, 1919.—In this memoir is painstakingly brought together all that is known of the Cenozoic corals within the area of the Caribbean Sea and the Gulf of Mexico. There are about 142 forms, 78 of which are new, and they are divided among 40 genera. It is quite evident that it is now very difficult to identify either recent or fossil corals, since their classification is dependent upon constantly changing calcareous structures. The coral animals are very sensitive to their environment, and this must be known in order to classify them expertly.

In stratigraphy, the author does not rely on single forms for age determinations, but whenever possible, on a combination of associated forms. In this connection he directs attention to the 54 forms of corals living within one half mile of each other on Cocos-Keeling islands in the lagoon (23), in the

barrier pools and on the barrier flats (20), and on the exposed reef (16). Of these only 5 are common to two and 1 to three of the habitats. We therefore see here that the percentage method of correlating an assemblage of fossil forms can have no value in determining the ages of the various ancient faunas.

On pages 238-332 are presented the "Conditions under which the West Indian, Central American, and Floridian coral reefs have formed, and their bearing on theories of coral-reef formation." Some of the author's conclusions are striking, as, for instance, that the great majority of offshore reefs, recent and Cenozoic, "are superposed on antecedent flattish basements or platforms" and that they have started to grow upon them "following considerable submergence . . . almost certainly due to differential crustal movement." "None of the American platforms were formed by infilling [of living corals] behind a barrier." The inner flat-bottom shallow seas of atolls are not due to submarine solution by sea water; they are antecedent bottoms on which constructional rings of organic material have grown upward.

"The Darwin-Dana hypothesis, in my opinion, is correct as regards the formation of offshore reefs during and after submergence; but as regards the formation of a prism of reef material, the upper surface of which forms a flat behind the barrier, their theory is wrong for every area on which we have definite information. . . .

"Semper, Alexander Agassiz, and others, who have maintained that barrier coral reefs have formed in areas of uplift, are correct, if the sum total of the movements since some date back in Tertiary time be considered, and their observations and deductions are valuable in that they emphasize these facts; but they are in error in that they failed to take into account that in many areas there is incontrovertible evidence showing submergence of the basements of the now-living reefs. . . .

"Sir John Murray invented a very stimulating hypothesis, and correctly emphasized the necessity of taking submarine-planation into account in studies of the basements of coral reefs.

"Daly did not originate the Glacial-control theory of coral reefs, but he is its principal exponent. The following ascertained relations of living offshore coral reefs conform to the demands of this hypothesis: (*a*) They are superposed on antecedent basement flats; (*b*) the amount of recent submergence, between 30 and slightly more than 20 fathoms, without deducting the amount of Recent up-building of the sea bottom, which probably is as much as a few fathoms, is of the order of magnitude expected from deglaciation; (*c*) the rate of growth of corals is known to be of such an order of magnitude as to account for the thickness of any known living coral reef by the growth of coral-reef organism since the disappearance of the last great continental glaciers." (326-328). C. S.

7. *Studies in Minor Folds;* by CHARLES E. DECKER. Pp.

89, 3 pls., 44 text figs. Chicago (University of Chicago Press), 1920.—In this work are described and illustrated a great many minor folds, some of which are associated with thrust-faults, occurring in the neutral area of the United States—neutral so far as major folding is concerned—and more especially in the region south of Lake Erie. Then are considered the various causes that develop folds and faults, resulting in the conclusion that "All of the larger and intermediate folds, and many of the smaller ones, are thought to be due to widespread tangential stresses in the rocks" (68). "The minor folds present most of the types common in major ones, though typical closed and recumbent folds are absent. . . . Most of the folds and faults are the result of widespread lateral compressive stresses; a few of the folds are pre-Pleistocene, possibly Permian or later, a few very small ones are Pleistocene, but most of them are post-glacial, and a number are post-terrace" (81-82). c. s.

8. *Lithologic Subsurface Correlation in the "Bend Series" of North-Central Texas;* by MARCUS I. GOLDMAN. U. S. Geol. Survey, Prof. Paper **129**-A, pp. 1-22, pl. 1, fig. 1, 1921.—This short but striking paper blazes out a new line of research in the study of buried sediments such as are so abundantly revealed in deep-well drilling for petroleum. The great value of autochthonous glauconite and phosphate as guides to ascertaining breaks in sedimentation is here made plain, and a scientific method for subsurface correlations in stratigraphy as well. The paper should be studied by all students of stratigraphy. c. s.

9. *The Hadrosaur Edmontosaurus from the Upper Cretaceous of Alberta;* by LAWRENCE M. LAMBE. Geol. Survey Canada, Mem. **120**, 79 pp., 39 text figs., 1920.—This beautifully illustrated essay from the pen of the late vertebrate paleontologist of the Geological Survey of Canada is in many ways one of the most ambitious papers which its author ever undertook. In it Lambe discusses the extent of his material, and, under the head of "Osteology," the detailed structure of the skull, mandible, the endocranial cast (brain), vertebræ, ribs, and fore limbs. He then defines the genus and species of which these specimens are the type, and passes to a discussion of the family of unarmored plant-feeding dinosaurs, the Hadrosauridæ, of which so many new forms have recently come to light as a result of the explorations carried on under the auspices of the Canadian Geological Survey and of the American Museum of Natural History. Lambe divides the family into three subfamilies, two of which were proposed by Barnum Brown of the American Museum. To these, the Trachodontinæ and Saurolophinæ, Lambe adds a third, the Stephanosaurinæ. A table of comparisons with the older term Hadrosaurinæ, substituted for Brown's Trachodontinæ, makes the division clear, amplified by figures of the several types of skull. This admirable work serves to emphasize yet further the irreparable loss which American paleontology has suffered in the untimely death of its talented author. R. S. L.

10. *The Nomenclature of Petrology;* by ARTHUR HOLMES. Pp. 284 (16mo). London, 1920 (Thomas Murby and Co.).—This excellent booklet is in the main a dictionary of petrologic terms. It defines about 1,300 names, giving the prevailing usage of each term, the original author and the date of its first use, and for the rock names the type localities. References are given for many terms, so that the subject matter can readily be traced to original sources. Appendices include not only French and German petrographic terms, briefly defined in English, but also the many Greek and Latin words whose roots enter into the nomenclature of petrology. The volume can be commended as filling a real want. ADOLPH KNOPF.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Carnegie Institution of Washington;* ROBERT S. WOODWARD, President. *Year Book No. 19, 1920.* Pp. xii, 424; illustrated. Washington, January, 1921 (published by the Institution).—This nineteenth Year Book of the Carnegie Institution, for 1920, is of particular interest because of the fact that the president, who has guided the affairs of the Institution so wisely for many years, announces his retirement, and that his place is to be taken by Dr. John C. Merriam, formerly of the University of California and elected to this new position on May 25, 1920. Other important personal changes have arisen through the death of the trustee, Mr. Henry L. Higginson, and of two associate investigators, William Churchill and Harmon N. Morse. To each of them, the President refers with keen appreciation of their life's work.

On the financial side, it is to be noted that of the total appropriations of $1,554,000.00, $927,000.00 has gone to the twelve large grants; $173,000.00 to minor grants; $250,000 has been placed in the reserve fund, and the balance has been expended for publications, administration, and insurance and pension funds. The publications of the year include 22 volumes of 3,840 octavo and 3,710 quarto pages; 16 additional volumes are now in press. The total number of volumes issued since 1902 is 424, embracing nearly 119,000 pages of printed matter. The president's report is followed by the statements of the departments by their respective directors, each giving the results of work accomplished and all of so much value, that it is not possible to go into detail. Perhaps the reader will turn with special interest to Dr. MacDougall's account of the work of the Botanical Research Laboratory at Tucson and at Carmel, California; that of Dr. Street on embryology; of Dr. Davenport on experimental evolution; of Dr. Mayor, on marine biology, at Tortugas, Florida; of Dr. Hale, at the Mount Wilson Observatory; of Dr. Bauer on terrestrial magnetism. In connection with the last-named, it is interesting to note the recent statement in "Science" that the magnetic survey yacht, Carnegie, arrived in San Francisco on February

19th, 1921, whence she will continue the cruise begun in October, 1919, having an aggregate length of 62,000 nautical miles. She is expected to return via the Panama Canal to Washington in October of the present year (1921). Dr. Day, in speaking of the work of the Geophysical Laboratory, gives interesting details in regard to the researches made into the various processes of making optical glass, called for by the demands of the war. Twenty papers on this subject were published during 1919; ten more in 1920, and still others are in preparation. When complete, the connection with this subject, as a manufacturing process, will cease. Dr. Day also mentions the work done on lines developed by W. H. and W. L. Bragg in locating the atoms of simple crystals by electrical means. Papers on this subject, by Dr. Wyckoff of the laboratory, will be found in the pages of this Journal, November, 1920, p. 317 and February, 1921, p. 138. An account is also given of the investigations of the gaseous emanations in connection with the Katmai Crater in Alaska, and other similar topics. The high cost of materials and labor have been keenly felt by the Institution, in all its lines, but its efficiency in publication and research has not been perceptibly impaired.

Recent publications of the Carnegie Institution are the following (continued from vol. **50**, p. 473):

No. 212. The Echinoderm Fauna of Torres Strait: its composition and origin; by HUBERT LYMAN CLARK. Quarto, pp. viii, 223; 38 plates. Department of Marine Biology, ALFRED G. MAYOR, director.

No. 274. Contributions to Embryology. Volume XI, papers 49 to 55 by different authors. Quarto, pp. 170; 15 plates, 12 text figures.

No. 292. Root development in the Grassland Formation. A correlation of the root systems of native vegetation and crop plants; by JOHN E. WEAVER. Pp. 151; 23 plates, 39 text figures.

No. 300. Grammar and Lau language, Solomon Islands; by WALTER G. IVENS. Pp. 64; 3 plates.

No. 301. The North American species of *Drosophila;* by A. H. STURTEVANT. Pp. iv, 150; 3 plates, 49 text figures.

No. 302. Metabolism and growth from birth to puberty; by FRANCIS G. BENEDICT and FRITZ B. TALBOT. Pp. vi, 213; 55 text figures.

2. *Collected Fruits of Occult Teaching;* by A. P. SINNETT, Pp. 307. Philadelphia, 1920 (J. B. Lippincott Co.).

Spiritualism—Its Present Day Meaning: A Symposium; edited by HUNTLY CARTER. Pp. 287, with 6 illustrations. Philadelphia, 1920 (J. B. Lippincott Co.).

The attitude of mind of one, who has been trained in physical science, towards the theories and reputed facts of what is known somewhat vaguely as Spiritualism, obviously depends upon what may be called his individual personal equation. It is probably more difficult for the physical student to feel in sympathy with

the writings of those interested in this line of thought than for others whose reading and investigations lie in different lines. The unexpected developments in physics the past two decades, however, are certainly such as to show that human knowledge has by no means reached its limits, particularly in directions not at once obvious to the senses. An intelligent person, therefore, should first of all be interested in what is being discussed and keep himself informed; he should be broad-minded in his attitude to the subject, and he should be in sympathy with genuine research in the psychical field.

The two volumes, the titles of which are given above, present the whole subject of occult teaching and spiritualism very thoroughly and from many different standpoints. Dr. Sinnett has already published two earlier books entitled "The Occult World" and "Esoteric Buddhism." His present work is well worthy of careful reading, even if his conclusions are not always accepted by those to whom theosophy does not make a strong appeal. The opening chapter discusses this world's place in the Universe. Others consider "future life—and lives"; "religion under repair"; theosophy from various points of view, and "the borderland of science" including astronomy (overt and occult) and "meta-science" with the problems of atoms and ether. Something of the author's point of view may be gathered from the opening sentences of a chapter on "Our visits to this World," which are quoted here. The author says:

"The materialist who regards human life as beginning in the cradle and ending in the grave is at all events consistent, though he insults Divine intelligence. But people who shrink from believing in final extinction, and nevertheless regard each new life as a fresh beginning, insult human understanding."

The second volume is a symposium containing chapters of very varying length written by between fifty and sixty authors, half of whom are specially noted on the cover page. The reader will find the subject of spiritualism looked at from many angles, in some cases directly opposed to each other. As the editor states, "a body of contributors whom I will call converts to spiritualism are perfectly satisfied that a great and good thing is happening. Another body who are not converted are uneasy lest a very bad thing is happening. But neither know what is really happening. For the moment all is conjecture." He also adds his conviction that "the general conclusion of the symposium is that the civilized human race are standing unconsciously within the threshold of a new era of the discovery and utilization of the miraculous powers in man. At the same time, the conditions of existence are so changing that the human mind is being transformed, and in such a manner that history will not repeat itself as it has the reputation of doing. In short, mankind for the first time in their history are about to realize their potential Self." The interest of the work is increased by a number of illustrations of spirit photographs which are certainly interesting whatever conclusion one may draw from them.

The questions sent to the contributors invited opinion on the coming of the new "psyche,"; its influence, material or spiritual; its trial by experts; and its utilization. The papers are grouped in two parts, the first treating of religion, philosophical and theoretical; then practical. The second part deals with science. Dr. Grenfell, in his brief note on "the moral sanction," well says that the subject should be handled "with open mind, with great caution, and rock bottom common sense."

3. *Types of Mental Deficiency;* by MARTIN W. BARR, M.D., and E. F. MALONEY, A.B. Pp. 179. Philadelphia, 1921 (P. Blakiston's Son and Company).—The leading author of this book some years ago wrote a standard treatise on Mental Defectives. He has had such extensive experience in the subject as chief physician of the Pennsylvania Training School for Feebleminded Children at Elwyn, Penna., that any work of his merits careful consideration.

The present volume is in the nature of a clinical album, containing as it does 188 half-tone illustrations of all types of defectives ranging from the lowest grade idiots to dementia praecox patients. These half tones are moderately clear. The accompanying descriptions are very informal, often containing facts which have no particular clinical significance. The very informality and unpretentiousness of the treatment, however, impart to the book a readable quality. We know of no more convenient way in which the general reader could 'visit' an institution and see all of the most interest and significant cases with running comments by the superintendent. Dr. Barr follows his old educational classification of mental defectives. He refuses to adopt the term Moron but employs instead the term "backward" and nowhere does he mention the name of Alfred Binet. No mental measurements of the cases are reported. The references to their vocational capacity, however, are interesting and suggestive.

ARNOLD GESELL.

4. *Practical Bank Operation;* prepared by L. H. LANGSTON. In two volumes: vol. I, pp. xxv, 370; vol. II, pp. 373-713. New York, 1921 (The Donald Press Company; price $8).—Practical Bank Operation has been admirably prepared by Mr. Langston under the direction of the Educational Committee of the National City Bank and is unique in this respect, that, while all ordinary functions of banks in general are stated and then in detail, described, there is nothing theoretical about it. Every operation described is taken, so to speak, from real life. It is the way that particular operation is handled today by *one particular* bank, a bank in many ways representative of the best in banking practice, for magnitude of business done, variety of services rendered, and efficiency in performance. The purpose of the book in fact is to show how a particular institution performs the functions enumerated. This institution being the largest of its kind, of necessity, has a highly organized department for practically every banking function, so that the small provincial bank

with a million or so of resources could by no means be laid out according to this elaborate plan, in fact the house could scarcely store the forms. But for any banker whose institution is large enough to require eight or ten separate departments, the book is full of meat. The arrangement of subjects is orderly and progressive and the treatment clear enough to furnish a good working basis for the remodeling of such a bank's system of business.

The book is an admirable text book for students of finance because the facts given are real ones and the operations described are actually in practice today in one of the best organized banks in the world. A farmer may be cynical of the "college professor" preaching with great confidence on the best methods of agriculture; he calls it book learnin', not practical. No such criticism applies to Mr. Langston's production.

The chapters on paying and receiving operations are worth the price of the book to any ambitious teller who thirsts for knowledge and proficiency and therefore advancement. More than that, any head of departments might well spend his time on the chapters touching his field, and then pass on the knowledge to his own lieutenants. Not many banks will derive practical benefit from the whole book because not many banks have occasion to perform such a multitude of functions. One bank's business is in the collection field, another specializes in foreign trade and exchange, another in farm credit, one is in a manufacturing center, another in a farming area, etc.

The banker himself will read with interest and profit perhaps one-half of the subject matter; the other half will be but the recital of organization and administration, containing nothing new for him, but the layman will skip but little.

Trust functions are treated briefly but readably, colored somewhat by New York laws and practice and by the very newness of the change by which National banks are now permitted to enlarge their fields and enter the intricate ramifications and byways of fiduciary business.

All in all Practical Bank Operations is an invaluable addition to banking literature. It is put together in an orderly way. The operations are thoroughly and clearly described, the charts and forms are many and helpful, and the whole is presented in good readable English. The man who reads these chapters and then is unable to give you a pretty good definition of a bank, is a hopeless case. DEAN B. LYMAN.

5. *First Pan Pacific Scientific Conference, Honolulu, Hawaii, Aug. 20-1920. Part I, Organization, Proceedings, Resolutions.* Pp. 46, Nov. 1920.—This report tells what was done by the one hundred delegates (fifty from Hawaii) to the Conference, regarding the scientific problems connected with the Pacific Ocean. A sketch of the organization is given, followed by the proceedings of the general sessions and the sections, and then by the resolutions adopted. It is the hope of the Pan Pacific Union to repeat these congresses every three years, and the personal contact of so

many delegates will do much to stimulate efforts toward a solution of the problems discussed. C. S.

6. *The Origin of Man and of his Superstitions;* by CARVETH READ. Pp. vi, 350. Cambridge University Press, 1920.—It is a large and complex problem that Professor Carveth Read would solve in this volume. There was a time toward the last third of the Oligocene epoch, some 2,000,000 to 3,500,000 years ago, when some Primate with wolfish instincts organized a hunting pack of his own kind. The venture was successful. It afforded a mixed and continuous diet; it also developed leadership and the opportunity to translate individual experience into group experience. The effect became cumulative until a point was reached where the individuals of the Primate pack outclassed all other Primates and became Man.

The last eight of the ten chapters are devoted to the origin of Man's superstitions, which appear to follow from the author's conception of Man's origin. GEORGE GRANT MAC CURDY.

OBITUARY.

DR. SHERBURNE WESLEY BURNHAM, the astronomer, died on March 11 in his eighty-third year. He was early connected with the Dearborn Observatory, Chicago; later at the Washburn Observatory at Madison, Wisconsin; the Lick Observatory in California; and finally at the Yerkes Observatory of the Chicago University. He was an active observer and is credited with having discovered nearly 1,300 double stars, the subject in which he was particularly interested.

DR. CHARLES HENRY FERNALD, professor of zoology and entomology at the Massachusetts Agricultural College from 1886 to 1910, died on February 22 in his eighty-third year.

PROFESSOR IRVING ANGELL FIELD, head of the department of biology in Clark University since 1918, died on February 14.

DR. FREDERICK JAMES VOLNEY SKIFF, for many years the able director of the Field Museum of Natural History, died on February 24 at the age of sixty-nine years.

DR. ALFRED GABRIEL NATHORST, the distinquished Swedish geologist and paleobotanist, died at Stockholm on January 20 in his seventy-first year.

PROFESSOR T. MIYAKE, the eminent zoologist of the Imperial University of Tokyo, died on February 2. His contributions to Science were largely in the department of entomology.

DR. JOHN CANNELL CAIN, the English chemist died on January 31 at the age of forty-nine. He was particuarly interested in dye stuffs and allied subjects to which he made numerous contributions.

DR. CARL TOLDT, professor of anatomy at the university in Vienna, died recently at the age of eighty years.

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

Art. XXV.—*Post-Glacial Warping of Newfoundland and Nova Scotia*; by Reginald A. Daly, Harvard University.

Contents.

Introduction.—The sensitiveness of the earth's crust to widely distributed loads seems to be proved by the systematic behavior of the crust after the partial or complete melting of large ice-caps. In every case the unloading has been followed by the uplift of the central part of the deglaciated surface. Examples are seen in Scandinavia, the British Isles, northeastern North America, British Columbia, Greenland, Spitzbergen, and Antarctica. For dynamical geology the physical meaning of the law is even more important than the discovery of the fact. Glacial loading of the crust and its unloading by deglaciation are analogous to actual experiments in testing the kind of response made by the material of the earth's interior to slowly applied stresses. The study of post-Glacial warping in the formerly glaciated regions has, therefore, significance for geodynamics in general. Explanation of the warping involves questions as to compressibility, elasticity of form, and the kinds of viscosity characterizing the inner shells of the earth. In particular, the relative importance of viscous flow and of elastic after-working should, if possible, be determined in the

case of the post-Glacial warping here considered. The writer spent the season of 1920 in the effort to add to the field data necessary for profitable attack on the difficult problem. Among the regions where special investigation has long been needed is Newfoundland. The observations there made have been quite insufficient for the mapping of the isobases or lines of equal uplift in post-Glacial time. Accordingly, strategic points along the Newfoundland coast were selected for study, in the hope that the essential data for this area could be secured and compared with the measurements already in hand for northeastern Labrador and for the Nova Scotia-New England coast.[1] Some time was also given to shore studies in Nova Scotia, where the zero isobase has yet to be definitely located and where the phenomena outside the upwarped area are particularly of importance for the geophysical interpretation of the post-Glacial deformation.

In 1900 the writer found what appeared to be good proof of post-Glacial uplift at St. John's, Newfoundland.[2] The amount of elevation then measured—more than 500 feet—was too large to be readily understood if the upwarping were either isostatic or purely elastic, but the record seemed advisable. For twenty years the writer has been suspicious of this result and a principal object of the 1920 field-work was to become better acquainted with the local facts at St. John's. The doubt was well justified, the post-Glacial uplift at that point now proving, practically beyond question, to be zero. One purpose of the present note is to advertise the mistake.

It is a pleasure to record the courtesy of the Newfoundland Department of Mines and Agriculture, who supplied maps and reports used during the investigation.

Methods of Determining Amount of Emergence.—As a rule the same method was employed as that which in 1900 proved successful along 600 miles of the Labrador coast. At each locality appropriate headlands were examined for evidences of wave-washing. On the well-exposed shores of both Labrador and Newfoundland, the lower limit of unwashed glacial drift could usually be located with considerable accuracy. Allowing for surf-

[1] For a bibliography of the subject, see H. L. Fairchild, Bull. Geol. Soc. America, vol. 29, p. 229, 1918.

[2] R. A. Daly, Bull. Museum Comp. Zool., vol. 38, p. 257, 1902.

fling, the highest strand was thus determined in the coastal belts. Of course raised beaches, sea-cliffs, sea-chasms, and fossiliferous beds were recorded and served as corroborative checks. Additional confidence in the value of the "washed" surfaces, as indicating the maximum reach of the waves, was attained when the successive determinations of emergence were found to be systematically related: the trace of the highest shoreline rising or falling along the coast at rates of the same order as those proved in northwestern Europe, New England, New York State, and farther west inside the margin of the glaciated area. Lack of time forbade thorough search for fossils in the many elevated beaches and clay benches. Only one discovery of the kind can be recorded; between Benoit's Cove and Curling, in the Bay of Islands, fragments of *Pecten islandicus*[3] were discovered in bedded clays about 75 feet above high-water mark, and a settler stated that he has found similar shells in the clays of the same slope at least 50 feet higher up.

Observed Amounts of Emergence.—Further study of the power of Atlantic storm-waves makes it probable that a few of the 1900 measurements for points in the highest shore-line are a little too high. This is particularly true of the estimates for Cape Rouge and Kirpon Island, Newfoundland, where the highest strand is respectively not much above the contours of 450 feet and 425 feet, instead of 505 feet and 450+ feet, as concluded in 1900.[4] On the other hand, the values given in 1900 for the points on the Labrador coast do not seem to need essential change.

The following table gives the elevations of the highest shore-line at points examined in 1920. The heights were determined by the use of two aneroids and of the heights marked on the Admiralty charts. The figures given are only approximate, but in each case the error is believed to be less than 5 per cent. The table also includes the revised figures for Cape Rouge and Kirpon Island, which were not revisited. Shoal Harbor is situated at the head

[3] Species kindly determined by Mr. R. V. Chamberlin of Harvard University.

[4] The height at which a breaker may be effective in washing off erratics from a glaciated ledge partly depends on the general slope, especially the seaward slope, of the ledge. The failure to allow sufficiently for this condition of wave-action, during the 1900 reconnaissance, has prompted the change in the estimates for Cape Rouge and Kirpon Island.

of a long fiord and this inland locality is not well adapted for the use of the main criterion of maximum emergence; the suggestion of uplift was found in the existence of well-defined, 70-foot benches of bedded, tenacious clays overlain by sand—apparently deposited in the fiord waters. No fossils were discovered, however, and the figure given for Shoal Harbor remains doubtful.

Elevations of the Highest Shore-Line above Mean Sea-level.

Locality Number on Map.		Feet.	Meters.
	Newfoundland, West Coast:		
1	Port-aux-Basques	0	0
2	Little River Railway Station	0	0
3	Stephenville Head	40 +	12 +
4	Curling	160	49
5	Bonne Bay	290	88
	Newfoundland, East Coast:		
6	St. John's and Conception Bay	0	0
7	Cape Bonavista	0	0
[8	Shoal Harbor	70(?)	21(?)]
9	Botwood	ca 170	ca 52
10	Lewisporte	190	58
11	Twillingate	240	73
12	Cape Rouge	ca 450	ca 137
13	Kirpon Island	ca 425	ca 130
	Labrador (Strait of Belle Isle):		
14	Cape St. Charles	ca 360	ca 110
15	Pleasure Harbor	ca 360	ca 110
16	Chateau Harbor	400	122
17	Red Bay	420	128
18	West Modiste	500	152
19	Forteau	500 +	152 +

Between Bonne Bay and the Strait of Belle Isle, a distance of 140 miles, the Newfoundland coast shows throughout abundant evidence of emergence, to the extent of at least 200 feet, and the uplift probably ranges between 300 and 450 feet. However, actual measurements of total uplift can there be made only at points several miles inland, where the land first becomes high enough. On account of the dense forest and lack of roads, this long stretch could not be properly studied in the available time. Similarly, time was lacking for the filling of the gaps between Bonavista and Twillingate and between Twillingate and Cape Rouge.

The general result is fairly definite. The zero isobase

crosses the west coast of Newfoundland in Bay St. Geroge, probably near Robinson's Head, 20 miles southwest of Stephenville. It crosses the east coast not far from the axis of Bonavista Bay. Its course inside the island is unknown. If the Shoal Harbor bench represents emergence, the zero isobase is rather sharply curved to the southward. To the northward of the zero isobase Newfoundland has been tilted to the south-southeast since its ice-cap melted. The maximum uplift is at the north end of the island, probably opposite Forteau, and is of the order of 500 feet. The average slope of the former level marked by the highest shore-line measures about 2.5 feet to the mile, or 1 in 2100. De Geer's conjecture as to the general type of deformation in Newfoundland is, therefore, in principle justified, though he placed the zero isobase too far south.[5] The isobases east of the Gulf of St. Lawrence tend to run concentrically around the Labrador center of glaciation. It is possible that Newfoundland has been faintly domed or arched and that the final mapping of the isobases will indicate the secondary influence of the independent ice-cap of Newfoundland on the character of the post-Glacial warping.

Conditions at St. John's, Newfoundland.—Fairchild has hypothetically drafted the isobases in the island on the assumption that the St. John's region was uplifted more than 500 feet, as the present writer concluded in 1900. The seriousness of this error warrants a brief statement of the facts. On the return journey from the Labrador coast in 1900, a few free hours were permitted at the city, time enough for climbing Signal Hill on the north side of the harbor. The massive, heavily striated ledges of quartzitic sandstones were found to be free from erratics and other glacial drift except beach-like accumulations of bowlders in the hollows of this extensive, rocky hill. The general surface is thus bowlderless up to the summit, 508 feet above sea. Across the harbor the ledges are thickly dotted with bowlders above the level of 575 feet. The conditions were apparently similar to those on the Labrador coast, where, allowing for surf-fling, the bowlder limit gave unequivocally the heights of the highest shore-line; in 1900 important emergence at St. John's seemed clear. The locality was revisited last summer, after the proofs of no post-Glacial emergence at Cape

[5] G. De Geer, Proc. Boston Soc. Nat. Hist., vol. 25, p. 454, map, 1892.

Bonavista and in the Conception Bay region had been obtained. Also near Signal Hill itself evidence was secured that this area had not risen, though the field notes of twenty years before were seen to be essentially correct, so far as the observations themselves are concerned. A full explanation of the peculiar conditions on Signal Hill is not easy to find. In part it may lie in the artificial removal of the erratics from the general surface of the hill, which was long fortified.

Glacial Striæ in Newfoundland and Southeastern Labrador.—Comparatively few records of the directions of glacial movement in this region have been published; those made in 1920, few as they are, seem worthy of note. In the following list they are indicated by locality names which correspond to numbers entered on the map.

		Range of Directions.	Mean Direction.
1	Port-aux-Basques	S.20°—40°W.	S.30°W.
3	Stephenville	S.65°—80°W.	S.75°W.
	Three miles west of 3.....	....	S.85°W.
4	Curling	S.85°W.—N.70°W.	N.85°W.
6	St. John's	S.85°—90°E.	Due E.
8	Shoal Harbor	....	Due E.
10	Lewisporte	....	N.15°W.
20	Flower's Cove	....	S.55°W.
21	Brig Bay	S.55°—65°W.	S.60°W.
17	Red Bay (Labrador)......	....	S.20°W.
18	West Modiste (Labrador).	....	S.15°W.

The directions of striation shown on the map without locality numbers are taken from the new (1919) geological map of Newfoundland, edited by the late J. P. Howley and published by the Department of Mines and Agriculture at St. John's; and from Plate 13 of the writer's 1900 paper.

So far as they go, these observations corroborate the now rather common assumption of glacialists, that Newfoundland had its own ice-cap or group of ice-caps, with centrifugal flow for the island in general. The flow of the latest glacial cover in the extreme north was, however, influenced by the trough of Belle Isle Strait, where the direction was southwesterly.

Weakness of Glaciation in Eastern Newfoundland.—On Bonavista peninsula and in the Lewisporte-Twillingate district, glacial drift is abundant, but in each case its

material was chiefly derived from the local formations. Far-travelled erratics are relatively rare. Beneath the drift one sees, at many sections, weathered rock grading upward into the drift, with generally no semblance of a moutonnéed surface, though the fresh rocks are strong

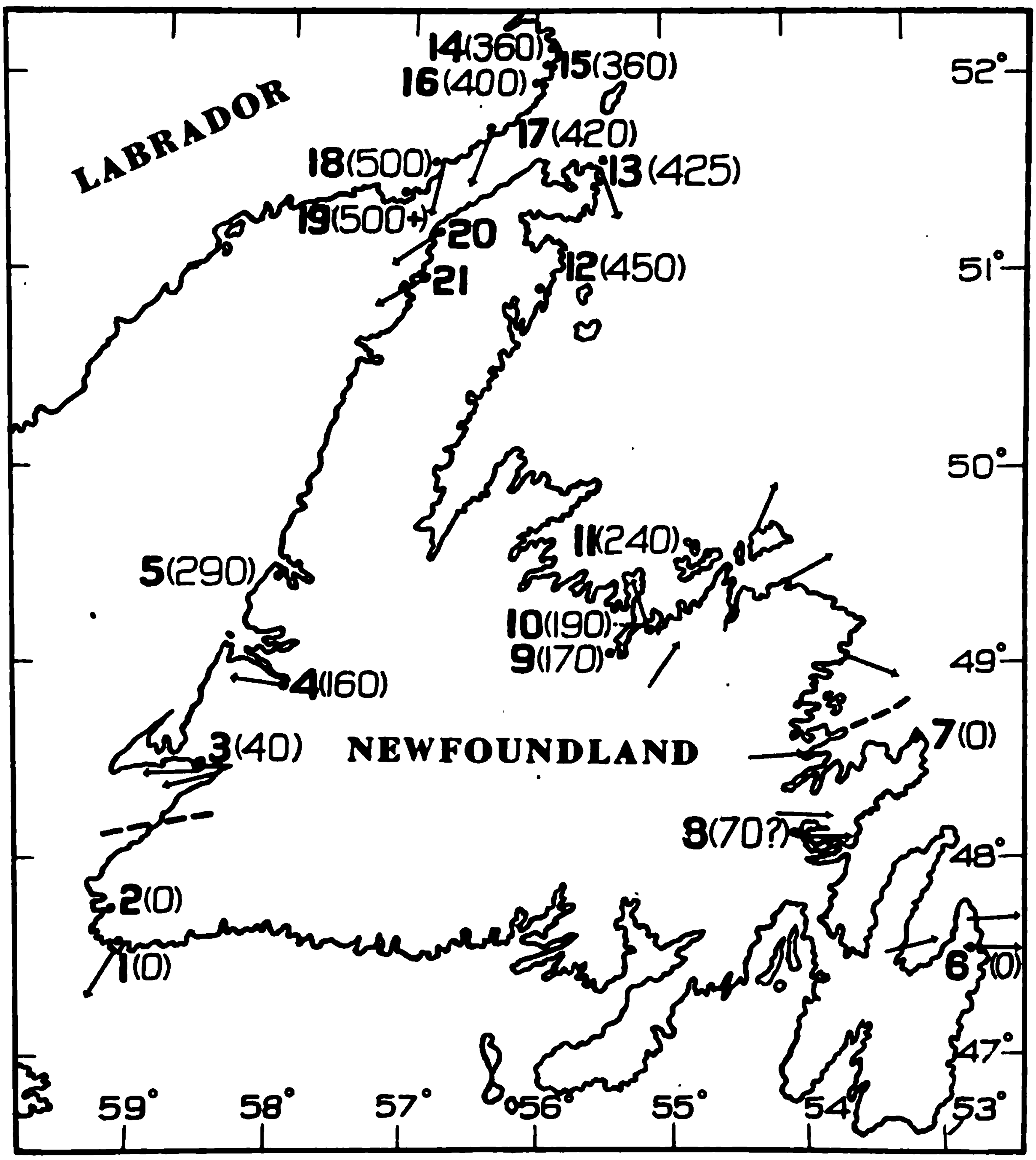

Fig. 1.—Illustrating post-Glacial warping of Newfoundland. Localities shown by dots and numbers; figures in brackets represent uplift in feet; broken lines near localities 2 and 7 represent approximate position of the zero isobase; glacial striæ shown by arrows.

and well adapted for striation and polishing. If the eastern coastal belt was covered by continuous ice of the Wisconsin stage, the thickness of the cap was probably less than the contemporaneous ice on Quebec or New

England. Incomplete as this field evidence is, it suggests a reason why the post-Glacial deformation of Newfoundland has been more controlled by the adjacent, masterful cap centering in Quebec than by its own load of ice; such a relation would be expected on the recoil theory of the deformation.

Recent Drowning of Southern Newfoundland and of Southern Nova Scotia.—Yarmouth, Nova Scotia, clearly lies outside of the area uplifted since the Glacial period. The zero isobase cuts across the shore somewhere between that point and Digby, where the uplift has been about 40 feet. A visit to Pictou Landing on Northumberland Strait showed that this locality lies south of the zero isobase.[6] The 1920 observations thus confirm the essential accuracy of De Geer's map, published in 1892. With the exception of a small area in the northwest, Nova Scotia has not been uplifted since the latest driftsheet was deposited. On the contrary, post-Glacial drowning is manifest all along the coast from Yarmouth to Halifax, and at Sydney. The same process has apparently affected most, if not all, of Cape Breton Island, and also the Newfoundland shore south of the zero isobase.

Causes of the Drowning.—The positive movement of the sea-level is in part referable to its general rise as the Pleistocene land-ice melted. If the rise of the glaciated tract north of the zero isobase was largely an elastic reaction of the earth, additional drowning outside the zero isobase is to be credited to gravitational disturbance. Under the weight of the ice-cap the material of the earth's interior was condensed. Each radial element was compressed with consequent lowering of its center of gravity. The observed lag in uplift implies that this condition existed for some time after the ice melted away. The horizontal component of the mass attraction exerted by the radial element on the ocean water was less before the elastic upheaval than after that upheaval. The mass of the element was not changed by its expansion, but the distribution of the mass was changed. The fraction of

[6] W. H. Twenhofel (this Journal, vol. 28, p. 147, 1909) found raised beaches, at altitudes above sea of about 25, 75, and 125 feet, in the shore-belt only 25 miles east of Pictou Landing. The present writer had no opportunity of visiting Twenhofel's locality (Arisaig). Since the latest drift-cover around Pictou has evidently not been washed by the sea, it is not easy to understand Twenhofel's results, except on the assumption that the Arisaig benches antedate the last glaciation.

the element measured by the amount of post-Glacial uplift was, during the application of the ice-load and the subsequent lag, represented by subsurface matter compressively condensed by the load. If the earth's compressibility varies according to the law deduced from seismograms, the center of gravity of the excess mass thus developed in depth may have been many hundreds of kilometers below the surface. The horizontal component of the attraction exerted by the element, at the earth's surface, would therefore be less than that exerted by the same mass when expanded because of unloading. A moderate rise of sea-level near and within the glaciated area should be expected.[7]

Drowning in the belt outside the zero isobase may also result from the isostatic restoration of crustal equilibrium after unloading. Jamieson, Munthe, Barrell, and the writer have found some evidence that the weight of an ice-cap produces a centrifugal, viscous flow of subcrustal material and consequent low bulges along the margin of the glaciated tract.[8] After the melting of the ice a return viscous flow toward the center of the glaciated tract should be expected. Barrell pointed out that, during the process of attaining final equilibrium, the crust underlying the marginal bulge should be lifted somewhat too high; and that, after the central region had nearly reached its final position, the bulge would slowly subside. Any coastal part of this belt would undergo progressive drowning for some time after the purely elastic deformation was completed.

Thus, in the marginal belt the shore contour at sea-level would be first affected by the return of water to the sea, a process accompanied by an immediate elastic uplift of the glaciated tract, with concomitant effect on mass attraction; then by the delayed uplift due to elastic afterworking and by accompanying viscous inflow, with further change in mass attraction; lastly, by slow subsidence in the bulged, marginal belt, entailing a positive movement of the sea in any coastal part of that belt. This third cause of drowning would persist long after the action of

[7] Cf. J. H. Pratt, The Figure of the Earth, 4th ed., London, 1871, p. 214; G. H. Darwin, Scientific Papers, Cambridge, England, 1910, vol. **3**, p. 29.

[8] T. F. Jamieson, Geol. Mag., vol. **9**, p. 461, 1882; H. Munthe, Geol. Fören. Stockholm Förhandl., vol. **32**, 1910—reprinted as Guide-book No. 25, Cong. Géol. Internat., Stockholm, 1910; J. Barrell, this Journal, vol. **40**, p. 13, 1915; R. A. Daly, Bull. Geol. Soc. America, vol. **31**, 1920, p. 303.

the other causes had ceased to be important, and it would not be surprising if the third cause is still locally at work.

The available evidence appears to warrant belief that the deformation of the earth's crust under glacial loads has been chiefly elastic. Assuming the largest probable volume for the marginal bulge around the composite North American ice-cap, computation seems to show the purely elastic deformation to have been from five to ten times greater than the deformation caused by viscous outflow. The very recent drowning of the marginal belt would therefore be quite moderate—in the regions here considered probably not surpassing a few tens of meters, even though the marginal bulge may have had a maximum height of 200 meters.

The testing of this theoretical set of deductions by field observations involves close dating of the submergence so clearly manifest in the coast region southwest of Boston and again along the southern shores of Nova Scotia and Newfoundland. In a case of this kind close dating is notoriously difficult, and the writer has been able to add few objective facts relevant to the date of drowning along the coasts studied in 1920. It is certain that the rise of sea-level is there very recent; the waves have not yet had time to cut wide benches in the little-resistant glacial drift which mantles most of Nova Scotia and certain stretches of the sea-front in southern Newfoundland.

On the other hand, tide-gauge records for eastern Canada, published by Dr. W. Bell Dawson, Superintendent of Tidal Surveys (Ottawa, 1917), show no measurable sinking of the land at Halifax, Charlottetown, and St. Paul Island (Cabot Strait) during periods of from 6 to 18 years. The New England coast seems to have been sensibly stable for at least one hundred years. Shimer describes proofs of submergence of the coast region at Boston within a period of 3000 years. He writes: "The remnants of the fish-weir, excavated on Boylston Street, give evidence of man in the Back Bay region of Boston, probably 2000 to 3000 years ago. He built this weir during a climatic period as warm as off the Virginia coast at present, and upon a sinking coast. Since its erection the region has sunk sixteen or eighteen feet and suffered a refrigeration to its present climate."[9] Certain facts suggest the necessity of postulating a recent, negative,

[9] H. W. Shimer, Proc. Amer. Acad. Arts and Sciences, vol. 53, p. 462, 1918.

eustatic shift of ocean-level to the extent of about 6 meters (20 feet).[10] The shift is tentatively placed in late Neolithic times. The complete failure of the corresponding bench to appear in southern Nova Scotia and southern Newfoundland suggests that the local drowning progressed after the eustatic shift of sea-level took place, that is, within the last three or four thousand years. Barrell's reasoning on the march of events during isostatic adjustment following the melting of an ice-cap would agree with this suggestion. The warping of the "25-foot" post-Glacial bench of the British Isles and the drowning of Neolithic deposits outside the zero isobase in England and Denmark may conceivably be explained in the same way, if the local British and Scandinavian ice-caps caused deformation like that connected with the Labrador ice-cap.[11] If, in each of the three regions, the local sinking occurred during post-Neolithic time, none of the regions would be likely to give convincing evidence of an earlier eustatic change of sea-level. On the other hand, strand-marks, corresponding to the higher position of sea-level in the glaciated area well inside the zero isobase, should not have been greatly disturbed during the final collapse of the marginal bulge. The remarkable low bench along the shore of the St. Lawrence estuary is a case in point.

The various facts and suggestions noted in the last few paragraphs suffice to show that the character and exact dating of the deformation in the marginal belt represent a delicate problem, which for geodynamics has scarcely less importance than a similar understanding of the uplift in the central area of a vanished ice-cap. Because of their specially favorable relations to the zero isobase and to the level-marking ocean, Nova Scotia and Newfoundland seem to be among the best of all the large areas in which to seek compelling evidence as to what really happened in the marginal belt.

[10] R. A. Daly, Geol. Mag., vol. 57, p. 246, 1920. At many well exposed headlands of Newfoundland the nearly or quite vertical sea-cliffs were seen to be continued under low-tide level from one-half fathom to two fathoms or a little deeper. This prolongation of the cliff below sea-level is the result of marine erosion and does not mean so much sinking of the land. The principle illustrated is important in connection with the problem of locating former sea-level from elevated rock-benches. At exposed places the bench levels are likely to be three to twelve or more feet below the high-tide level ruling at the time when the benches were cut.

[11] Cf. W. B. Wright, Geol. Mag., vol. 57, p. 382, 383, 1920.

ART. XXVI.—*New Camels in the Marsh Collection;* by RICHARD S. LULL.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

The Oligocene camels in the Marsh Collection consist of a number of skulls and other skeletal material. Those from the White River Oreodon beds are clearly referable to three of the known species of *Poëbrotherium* and add nothing to our knowledge of these forms. From the Protoceras beds, on the other hand, comes one apparently new species, while from the upper John Day are several specimens worthy of description.

Pseudolabis (Paralabis) matthewi, subgen. et sp. nov.

(Fig. 1.)

Holotype, Cat. No. 10167, Y. P. M. Upper Oligocene (Protoceras beds), Sturgis, South Dakota.

The type material consists of a poorly preserved skull with the third incisor and a complete series of cheek teeth.

Distinctive characters.—Size somewhat larger than *Poëbrotherium labiatum*. Skull mutilated so that few characters are observable. Auditory bullæ less rounded than are those of *Poëbrotherium,* although fully as large. Tympanohyal recess more widely open and inner posterior lobe thus narrower, more as in the later camels. Rear of orbit not preserved, but zygomatic arch and adjacent bones are rather heavy, so that its closure is probable. Infra-orbital foramen above P^4, palatal foramina opposite the posterior half of P^3.

Dental formula: $I^{3?}$, C^1, P^4, M^3. Alveoli of $I^{1\text{-}2}$ not preserved, I^3 caniniform, recurved, probably equal to, if not exceeding, the canine in size. Canine lacking, alveolus elliptical, separated from I^3 by a short diastema. P^1 double-rooted, crown not preserved, larger than P^2, and separated from the adjacent teeth by diastemata, of which the anterior one is nearly two times the greater. P^2 to M^3 form a compact series, the crowns of medium height. Molars with prominent parastyle, mesostyle, and external ribs, no internal basal pillars present. P^3 with internal cingulum, and P^4 with an accessory internal crest connecting the crescent with the rear of the tooth, suggestive

of the double internal crescent described by Matthew in *Pseudolabis dakotensis,* although by no means so well developed.

Compared with its contemporary from the Protoceras beds, *Pseudolabis dakotensis,* the present species resembles the latter in the comparable cranial details, the relative spacing of the anterior teeth, the character of the third and fourth premolars, and in the actual size of M^3. It differs from Matthew's form in the smaller size, more attenuated muzzle, relatively larger C^1 and I^3, and relatively much smaller premolars, as the table of measurements shows. The presence of the mesostyle, absent in the molars of *P. dakotensis,* is also very distinctive. Some of these distinctions, as, for instance, the relatively smaller canine and I^3 in *P. dakotensis,* might be sexual, were their possessor not a considerably larger animal. The presence of the mesostyle and the relatively more elongate muzzle and smaller premolars of the new form are both progressive characters which its contemporary lacks, showing the two to be divergent species, as the time and space limitations render the derivation of one from the other impossible. The gap so formed between them is certainly of subgeneric and possibly of generic rank.

Fig. 1.—*Pseudolabis (Paralabis) matthewi*, subgen. et sp. nov. Holotype. Palatal aspect. A little less than one half nat. size.

The present form differs from *Poëbrotherium* in the larger size, the character of the auditory bullæ, the more prominent mesostyles, the relatively larger and more caniniform I^3, and the more attenuated muzzle, with, as a consequence, the longer diastemata, especially between the canine and P^1. Whether or not the rear of the orbit would prove a contrasting character can not be shown in the present specimen. In the type of *Pseudolabis dako-*

tensis the closure of the orbit is a notable distinction from *Poëbrotherium.* The present form is referred to the genus *Pseudolabis,* subgenus *Paralabis,* subgen. nov., and the specific name is given in recognition of the very high attainment of Doctor W. D. Matthew as a leader in paleontologic research.

Measurements.

	Y. P. M. 10167 *P. matthewi* mm.	Ratio	A. M. N. H. 9807 *P. dakotensis* mm.
Length, I^3 to condyle	219.0		
I^3 to M^3	122.0	0.88	138.5
C^1 to M^3	108.5		
P^2 to M^3	69.5	0.83	83.7
I^3, ant.-post. diameter	7.7		
I^3, length of crown	14.5		
Diastema, I^3 to C^1	5.5		
C^1, length of alveolus	7.7		
Diastema, C^1 to P^1	15.5		
Diastema, P^1 to P^2	10.0		
Length, P^2	8.0		
P^3	9.5		
P^4	9.5		
M^1 to M^3	43.5	0.906	48.0
M^1	12.5		
M^3	17.0		

John Day Camels.

Of the four species of camels which have been described from Oregon, two, *Paratylopus (Gomphotherium) sternbergi* (Cope) and *P. (G.) cameloides* (Wortman), come from the John Day horizon, while the two others, *Miolabis transmontanus* (Cope) and *Procamelus altus* Marsh, are from newer rocks. The Yale collection includes the type of the last-named species, while of John Day material there are at least six specimens, some of which pertain to *Paratylopus cameloides,* the others being evidently new. *P. (G.) sternbergi,* which comes from an older horizon, is apparently not represented at Yale.

Paratylopus (Gomphotherium) cameloides (Wortman).

(Figs. 2-4.)

Type material contained in the American Museum of Natural History, as follows: Cat. No. 8179, holotype,

mandibular ramus; Cat. No. 7915, paratype, upper dentition; Cat. No. 7912, paratype, almost complete fore limb, as well as several other fragments. Type locality, the Cove, John Day basin, Oregon. Type level, upper John Day (Promerycochœrus beds), uppermost levels, several hundred feet above that of *P. (G.) sternbergi.*

The association of this material under one species is open to question. The mandible, No. 8179, which is the first mentioned type, and therefore the holotype, is distinguished by increased size over that of *P. sternbergi,* as well as by the absence of diastema between the lower canine and outer incisor. The Yale specimen, Cat. No. 10921, comes from the type locality, and in so far as it is preserved, agrees in detail with the type. It consists of a muzzle, both upper and lower incisors, still embedded in the matrix, together with the lower canines, P_1 of the right side, and a detached fragment of the right ramus containing P_4, M_{1-2}. Fragments of the superior molars, premolars and canine are also present. There is no difference in size, except that in the type, P_1 is somewhat smaller and P_4 of the latter bears a small posterior cusp on the external face which is lacking in the Yale specimen. The teeth of the upper series (No. 7915, A. M. N. H.) are too large, especially the premolars and first molar. The ratios of Wortman's own measurements show the discrepancy at once, thus:

	P. sternbergi	Ratio	*P. cameloides*
	mm.		mm.
Length of upper molars and P^{2-4}	60	0.72	83
Length of lower molars and P_{2-4}	65	0.67	97

as the two series of *sternbergi* belong to the same individual.

Thus, the upper dentition of No. 7915, A. M. N. H., paratype, pertains to a somewhat larger and more conservative, although contemporaneous, specimen (see below).

Cat. No. 10090, Y. P. M., is also probably to be referred to *Paratylopus cameloides,* although an immature individual. This specimen, consisting of a skull and jaws collected by L. S. Davis in 1876 in the John Day valley, Oregon, is from the same horizon as the type. It consists of the skull from the middle of the orbits forward, the hinder part not being preserved. The milk dentition is present except for the upper median incisors. M_2 is not

erupted, M^2 was not in use although fully visible in the jaw, and both upper and lower third molars are not formed.

Distinctive characters.—Skull small, very slender, muzzle elongated. Facial vacuity apparently present. Deep depression on either side of face in maxillary, the pre-orbital pit, preceded by a slight swelling, the infra-orbital foramen over P^4. Premaxillaries very delicate, extending back to above P^2 and forming an extensive union with the nasals.

Upper deciduous incisors small, somewhat spatulate, and spaced. Deciduous canine isolated by long diastemata. The small, apparently permanent first premolar is

FIG. 2.—*Paratylopus cameloides* (Wortman). Juvenile. Skull and jaws, right aspect. × 3/5.

also isolated, its crown not fully erupted; it is triangular, trenchant, and apparently double-rooted. Dp^2 to M^2 form a continuous series with prominent external styles and buttresses, especially upon the molars. Dp^2 simple, laterally compressed, with one prominent cusp, flanked anteriorly by a lesser one, externally supported by a buttress. Dp^3 elongate, irregularly triangular, with one anterior and two posterior crescents. Dp^4 molariform, with a small internal pillar and prominent mesostyle. Molars tending toward hypsodonty, M^1 with small internal pillar and strong parastyle, mesostyle, and external buttresses.

The apparently deciduous inferior incisors and canine form a continuous series without diastema, are spatulate and procumbent. Canine incisiform, somewhat smaller

than incisors. P_1 apparently permanent, partly erupted, but unused, compressed, trenchant. Dp_{2-4} present. Dp_4 three-lobed, otherwise molariform. M_1 the only erupted molar.

Ramus very slender, gracefully curved, symphysis long. Mental foramen of left side just below anterior margin of P_1. This form differs from *Poëbrotherium* chiefly in the great elongation and attenuation of the muzzle, giving an actually greater antero-posterior dimension to the premaxillaries and a relatively slenderer jaw and longer symphysis. The lack of caniniform teeth is evidently due, in part at least, to the permanent ones not having erupted, and the diastemata are relatively much greater. While the nasals are not preserved throughout their entire length, it is doubtful whether they ever extended

FIG. 3.—*Paratylopus cameloides* (Wortman). Juvenile. Palatal aspect of skull. × 3/5.

so near the tip of the muzzle as in *Poëbrotherium*, although their relative extent, as compared with the maxillaries, was similar.

The lower jaw, on the other hand, has very much the contour of the type of *Paratylopus cameloides*, with which it also agrees in the lack of diastemata between the lower incisor and canine teeth. The position of the mental foramen also is in practical agreement, although it varies in the two rami of the jaw, extending further back on the right side. The size of the permanent molars approximately corresponds.

Two other specimens may be referred to *Paratylopus cameloides*. These are, first, Cat. No. 10917, Y. P. M., collected by William Day in 1875 from the upper John Day beds at the Cove, John Day River, Oregon, and consisting of the superior maxillary, containing the dentition from the canine back, except that the crowns of P^{2-3} are broken away. This is an old animal, with M^1 worn almost

to the roots. The proximal portion of a left metatarsal is also present. There is, however, no direct evidence that the two bones pertain to the same individual.

The second specimen is Cat. No. 10922, Y. P. M., collected in 1875 by L. S. Davis from the same level in Haystack valley 10 miles below the Cove on the John Day River. It consists of a right mandible, dorsal centra, astragalus, and both femora and tibiæ, all four incomplete as to their shaft.

Distinctive characters.—Canine caniniform, sharply recurved, the section ovate. P^1 two-rooted, separated from the preceding and following teeth by extensive

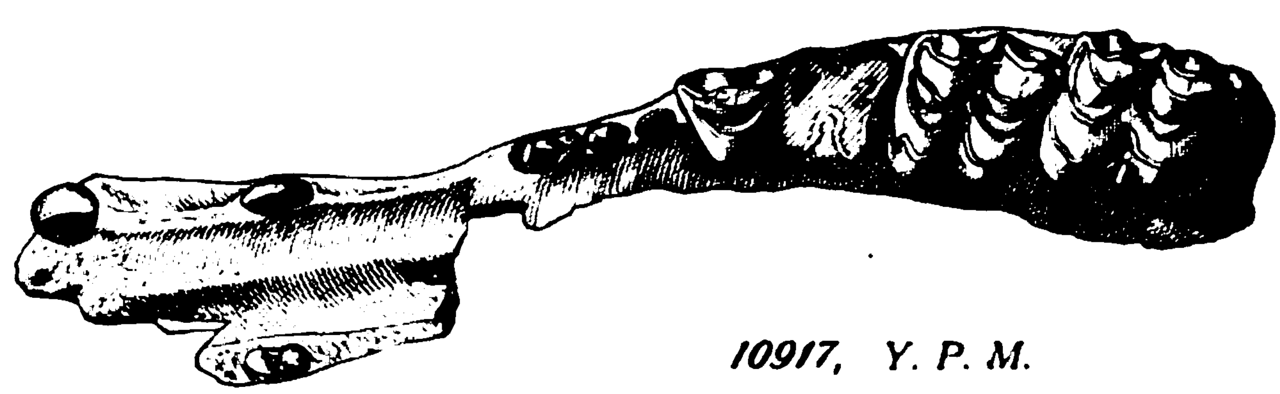

FIG. 4.—*Paratylopus cameloides* (Wortman). Crown view. × 3/5.

diastemata, of which the posterior one is somewhat the longer. Crown compressed, rounded by wear, with a distinct posterior cutting edge. P^4 sub-triangular, external buttress inconspicuous. M^1 characterless through wear, markedly smaller than the succeeding molars. M^2 and M^3 with well developed mesostyles, external buttresses, and rather pronounced internal basal pillars. On M^1 the internal style may have been present, but if so, has been worn away. Enamel of teeth rugose. Muzzle rather slender. Marked depression above and behind P^1. Infra-orbital foramen above posterior margin of P^4. Palatine foramina not preserved.

Compared with the type lower jaw of *P. cameloides*, there is a close agreement, as the molar teeth fit accurately. There is in the type, however, no trace of external basal pillar corresponding to the internal basal pillars in the present specimen, but this has been shown to be an inconstant feature within a species.[1] The teeth in the type also appear more hypsodont, but the Yale specimen shows a much greater degree of wear. With the referred superior dentition (No. 7915, A. M. N. H.), however, there

[1] See R. S. Lull, this Journal (4), 50, 104, 1920.

is more discrepancy, as the first molar and premolars are relatively markedly smaller, as compared with molars 2 and 3 of the upper series, thus indicating a greater degree of evolutionary advance.

Measurements.

	mm.
Length, P_2 to M_3	78.5
Diastema, C to P^1	16.0
Diastema, P^1 to P^2	20.0
P^4, ant-post. diameter	11.0
P^4, transverse diameter	10.0
M^1, ant.-post. diameter	13.0
M^2, ant.-post. diameter	17.3
M^2, transverse diameter	16.5
M^3, ant.-post. diameter	20.0
M^3, transverse diameter	17.4

The proximal third of a left metatarsal is associated with the jaw and is coössified by the plantar (palmar of Peterson) processes. It corresponds in every way with the jaw, but may not pertain to the same individual, as the same lot contained non-camel material as well. The component elements are very closely applied, so much so that were it not for a film of matrix between their approximated surfaces, they would appear to be coössified throughout. This very close approximation, together with the final fusion of the plantar processes,[2] is probably due to the age of the individual. It is in agreement with *Oxydactylus* (see below).

Measurements of cannon-bone.

	mm.
Proximal width	25.9
Ant.-post. diameter over plantar processes	24.4
Width of shaft, 50 mm. below summit	15.6

Specimen No. 10922, Y. P. M., consists of a right mandible, the teeth of which show fair correspondence with those of the upper jaw. One abnormal peculiarity, however, is a supernumerary P_1, the presence of which prevents an accurate fit with an upper jaw, No. 10917, as the smaller forward tooth interferes with P^1. Both first lower premolars are double-rooted, with trenchant

[2] In the type of *Paratylopus sternbergi* (Cope) in the American Museum the plantar processes are entirely separated throughout.

crowns, and are preceded and followed by diastemata of less extent than in the upper jaw. No other peculiarities are to be noted, except that there is a low basal pillar between the two outer crescents of M_1 corresponding to those between the inner crescents of M^2 and M^3. The character of the enamel corresponds to that of the upper dentition. The jaw is slender, with a nearly straight inferior margin, except toward the symphysis, where it is deflected downward. The mental foramen lies beneath the anterior P_1. The preserved portions of the limb bones and dorsal centra show nothing distinctive.

Measurements of lower jaw No. 10922.

	mm.
Length, P_2 to M_3	85.0
First P_1, ant.-post. length	5.8
Second P_1, ant.-post. length	7.7
Diastema, P_1 to P_2	12.3
P_2, length	9.2
P_3, length	11.3
M_2, length, ant.-post.	15.5
M_2, transverse diameter	10.6
M_3, ant.-post. diameter	21.6
M_3, transverse diameter	10.0
Depth of jaw at P_{1-2} diastema	14.4
Depth of jaw outside beneath ant. part M_3	24.5
Thickness of jaw beneath ant. part M_3	13.0

Paratylopus wortmani, sp. nov.

(Fig. 5.)

Holotype, Cat. No. 10884, Y. P. M. Upper Oligocene (upper John Day), Haystack valley, John Day River, Oregon.

The material upon which this new species is based consists of the anterior part of the upper jaws, four cervical vertebræ, humeri, ulno-radius, carpalia, metacarpalia, distal ends of both femora, proximal end of a tibia, and portions of both metatarsals. The premaxillaries are preserved, together with the maxillaries back as far as the root of the left P^2.

Distinctive characters.—The incisors were all present, I^3 being the largest, caniniform, and separated by a long diastema from the true canine tooth. In *P. cameloides*, this diastema must have been very short, as there is none

between inferior I_3 and C_1. The caniniform I^3 of the present form would seem to imply such an inferior diastema as in *Oxydactylus*. The canine is a well developed recurved cone. P^1 is two-rooted, compressed laterally, crown not preserved, but apparently less caniniform, separated from the adjacent teeth by diastemata of somewhat similar extent. The premaxillaries are prolonged backward, forming a premaxillo-nasal contact of considerable extent.

FIG. 5.—*Paratylopus wortmani*, sp. nov. Holotype. Right lateral aspect of muzzle. Nat. size.

Measurements.

	mm.
I^3, ant.-post. diameter	7.5
I^3, transverse diameter	5.0
C, ant.-post. diameter at base	9.3
C, transverse diameter	6.8
P^1, ant.-post. diameter of roots	8.7
P^1, transverse diameter of roots	3.5
Diastema I-C	12.0
Diastema C-P^1	17.4
Diastema P^1-P^2	22.4

Of cervical vertebræ, there are present the atlas, and an entire cervical V, to which are articulated nearly half each of cervicals IV and VI. These bones, while somewhat more primitive, resemble those of *Oxydactylus longipes* Peterson, although differing in dimensions, as the comparative measurements show.

Measurements.

	Cat. No. 10884 Y. P. M. mm.	Ratio	*O. longipes* mm.
Greatest length of atlas	64.5	0.806	80
Greatest breadth of atlas	58	0.773	75
Greatest length, cervical V	114	0.674	169
Length of centrum, cervical V	97	0.647	150

The ratios show somewhat slenderer bones in No. 10884, together with a relatively long atlas.

The humerus differs from that of *O. longipes* in the form of the trochlea, which shows a greater obliquity in the latter. The proximal end is not preserved, and herein our John Day form resembles Wortman's figure of *P. cameloides* paratype, No. 7912, A. M. N. H. (see above). In some respects the trochlea suggests the one, in others, the other. Judging from the figure, there is a close agreement with *cameloides* in size.

The right ulno-radius is essentially complete, lacking only a very small portion of the distal articulation, which is supplied by its mate. The fusion between the two bones is so complete that the line of demarcation between them is practically obsolete except at the distal end. The element resembles very closely that figured by Wortman for *P. cameloides,* from which it differs chiefly in apparent dimensions as taken from the figure. From *Oxydactylus,* it differs in the greater distinctness of the distal end of the fibula and in certain minor details of the proximal end.

Measurements.

	P. cameloides mm.	Ratio	No. 10884 Y. P. M. mm.	Ratio	*Oxydactylus longipes* mm.
Humerus, length	192*	1.12	215†	0.68	315
transverse diameter, mid-shaft ...			17		
transverse diameter, distal end ...			38		
Ulno-radius, length	285*	1.07	305	0.69	440
width, prox. end			34	0.72	47
width, dist. end			35.5		
width, mid-shaft			23	0.66	35

* From Wortman's figure.
† Estimated.

The metacarpus resembles that of *Oxydactylus,* except in the apparent degree of development of the vestigial metacarpals II and V, which Peterson speaks of as small,

flat, rugose ossicles, on the sides of the functional third and fourth metacarpals. Metacarpal II was apparently free, as there is a distinct facet on the outer posterior corner of metacarpal III contiguous to, but beneath, the trapezoid facet. Metacarpal V, on the other hand, is represented by a small rugose knob thoroughly coalesced with metacarpal IV. Herein, as with the cervicals, the form under consideration is simply more primitive than is *Oxydactylus*. No mention of these details is made by Wortman, who merely figures the anterior metapodials and records their length. There is no trace of coössification of the metacarpals, but their flat, somewhat rugose surfaces were closely applied.

Measurements.

	P. cameloides mm.	Ratio	No. 10884 Y. P. M. mm.	Ratio	*O. longipes* mm.
Metacarpals:					
Length	228	0.964	220	0.638	345
Breadth, combined, at mid-shaft	21*	1.00	21	0.637	33*
Breadth, prox. end	28.8*	1.02	29.5	0.638	46.2*
Breadth, dist. end, mcp. III	16.8*	0.905	15.2	0.660	23
Breadth, dist. end, mcp. IV	16.2*	0.969	15.7	0.683	23
Average		0.972		0.651	
Femur:					
Trans. diameter, dist. end			44.6	0.666	67
Diameter, mid-shaft			22	0.733	30
Tibia:					
Max. ant.-post. diameter, prox. end			61	0.726	84
Transverse diameter, prox. end.			48.3	0.690	70

* From the illustrations.

The phalanges again are comparable to those of *Oxydactylus*, the ungual being compressed and deer-like.

Measurements.

	Cat. No 10885 Y. P. M. mm.	Ratio	*O. longipes* mm.
Length of prox. phalanx	46	0.836	55
Length of median phalanx	22.2	0.793	28
Length of ungual	18.5	0.740	25

Specimen No. 10884, Y. P. M., is distinct from either *Paratylopus sternbergi* or *cameloides*, chiefly by its larger size, the robustness of the caniniform teeth, and the length of diastema between I^3 and C^1. It is not clear, however,

that it is distinct from the paratypes of the *cameloides* description, especially the upper dentition (No. 7915, A. M. N. H.). It seems fitting, therefore, to name it in honor of Doctor Jacob L. Wortman, the describer of *P. cameloides,* who for a time rendered so eminent a service to the science of vertebrate paleontology.

Peterson,[3] speaking of *Oxydactylus,* says this phylum appears to be divergent from that of the true camels and that we are at present able to trace it with some certainty to the genus *Protomeryx* of the Upper Oligocene. Matthew,[4] however, restricts the use of the term *Protomeryx* to the two species *P. halli* Leidy and *P. campester* Matthew, and uses the new subgeneric term *Paratylopus* to include what were originally described as *Gomphotherium sternbergi* (Cope) and *G. cameloides* Wortman, together with his new species *primævus,* which he makes the type of *Paratylopus.* His derivation of *Oxydactylus* is from *Paratylopus* through *Miolabis,* the restricted *Protomeryx* being in the direct line of camel evolution and leading to *Protolabis* and *Procamelus.* As Peterson considers *Protomeryx* to be a synonym for *Gomphoides* (preoccupied), it is probable that he and Matthew are referring to the same group under different names, and hence their statements agree. The Yale material thus briefly described certainly bears this out, as it differs from the later *Oxydactylus* mainly in its greater primitiveness.

[3] O. A. Peterson, Ann. Carnegie Mus., 2, 472, 1904.
[4] W. D. Matthew, Bull. Amer. Mus. Nat. Hist., vol. 20, 211-215, 1904.

ART. XXVII.—*Leptauchenia Leidy and Cyclopidius (Pithecistes) Cope, with descriptions of new and little known forms in the Marsh Collection;* by MALCOLM RUTHERFORD THORPE.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

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INTRODUCTION.

The genera *Leptauchenia* and *Cyclopidius* are the most peculiar of all the Oreodontidæ. *Pithecistes* Cope is considered identical with *Cyclopidius.* The first genus is fairly well known, the whole skeleton of *L. decora* having been mounted, but not as yet fully described. *Cyclopidius* is known only from skulls and jaws.

Leptauchenia decora was apparently the most numerous, judging from the number of individuals represented in the Marsh and other collections.

The taxonomy of these genera will be discussed in a later paper where the Oreodontidæ as a family are considered. It is sufficient to remark here that they represent the climax of at least a part of this family, which began in the Eocene, reached its greatest development in the Oligocene, and became extinct through these and other highly specialized and peculiar forms in the Miocene or early Pliocene. *Leptauchenia* represents an earlier geologic epoch than does *Cyclopidius (Pithecistes),* the latter also showing more marked peculiarities.

The material in the Yale Museum serves admirably to amplify our knowledge of these genera, both in the description of referred specimens and of new species. The excellent illustrations were made by R. Weber.

Description of Species.

Leptauchenia decora Leidy 1856.

This species is represented in the Marsh Collection by more than forty individuals. Apparently the elements of the skull which were most resistant to destruction were the rami and maxillæ with molars. Specimens of this species have been found on the North Platte River, at Crow Buttes, Fort Mitchell, Lawrence's Fork, Court House Rock, Scott's Bluff, Omaha Creek, Rattlesnake Butte (near Chadron), and many from Pumpkin Creek—all in Nebraska; and one specimen from Spring Creek, near Camp Baker, Montana, collected by Edward S. Dana and George Bird Grinnell. The description is taken from various individuals, but especially from Cat. Nos. 10119 and 10121.

Specific Characters.—The skull is somewhat smaller than that of *Oreodon gracilis,* and broader, shorter, and lower. The lacrymal fossa is small and shallow, and the infra-orbital foramen is above the middle of P^3. The malar is remarkably robust. The bullæ are much inflated and oval in outline. The palate is nearly flat, while the palatonarial border is opposite the posterior margin of M^3. The orbits are large, oval-shaped antero-posteriorly, and look chiefly outward; the facial vacuities are large and extend somewhat posterior to the anterior orbital border; the ramus is similar to that of *Oreodon,* except that the posterior area is of greater proportionate width and depth; the masseteric fossa is large and relatively deep; the inferior border is straight; the auditory meatus is large, situated a little in advance of and well above the line of the occipital condyles; the paramastoids are plate-like, are in contact with the bullæ, and extend downward but slightly below the inferior border of the bullæ. The dentition shows the full number of teeth common to *Oreodon,* that is, forty-four. Both molar-premolar series are crowded and the latter somewhat reduced. The molars are more nearly uniform in size reduction from M^3 to M^1. These teeth are very hypsodont and the external styles are very well developed.

Measurements.

(Cat. No. 10121, Y. P. M., unless otherwise indicated.)

	mm.
Skull, length, occip. condyle to canine inc., approx.	107
Bizygomatic diam., approx.	74
Diam. of postorbital constriction	20.5
Max. width of brain-case	34.5
Width above P^2	27
Width between middle of orbits	38
Ant.-post. diam. of facial vacuity, approx.	30
Ant.-post. diam. of bulla (Cat. No. 10120)	21
Transverse diam. of bulla (Cat. No. 10120)	18.5
Depth of malar below middle of orbit	14
Depth of paramastoids below inferior border of auditory meatus	26
Ramus, depth, coronoid to angle	55
Depth below M_2	18
Total length, approx.	90
Superior molar series, length	28.5
Superior premolar series, length (Cat. No. 10120)	17-20
Inferior molar series, length (Cat. No. 12668)	32
Inferior premolar series, with P_1, length (Cat. No. 12668)	20.5

Leptauchenia cf. *decora* Leidy.

A skull with jaws attached, not readily identifiable with any of the three described species of this genus, was collected in 1914 by John T. Doneghy, Jr., at Rattlesnake Butte, about 6 miles southwest of Chadron, Nebraska. This skull is that of an immature individual, in which neither superior nor inferior third molar is erupted. It was found in the Lower Miocene beds, and I believe represents a form intermediate in size between *L. decora* and *L. major*.

This specimen, Cat. No. 12221, Y. P. M., is exceedingly well preserved, with the exception of the superior part of the muzzle in advance of the orbits, including the superior incisor border. The chief characters may be set forth briefly. The total length of the skull is approximately that of *L. decora*, but in the fully adult form it must have been somewhat longer. The sagittal crest is short and has a nearly straight contour. From the junction of the temporal ridges, the upper contour descends steeply to the tip of the nasals, giving an anthropoid appearance from a lateral view. The orbits are small and look chiefly upward and outward, in which

respect it is more like *L. major,* although this feature is more pronounced than in the latter species. The bregma, the junction of the sagittal and coronal sutures, is situated considerably farther in advance of the junction of the temporal ridges than in *L. decora* and holds more nearly the position seen in *L. nitida.* In *L. major* the bregma is located at the junction of the temporal ridges. The malar below the orbit is more robust and deeper in this submature specimen than in a fully adult *L. decora.* The infraorbital foramen is above the interval between P^2 and P^3. The bullæ are of different shape than in any other species of the genus, but whether this is due to adolescence or not I have no way of determining at present. In outline, they are roughly circular and much inflated. They are proportionally as large as in *L. nitida,* and absolutely larger than in *L. decora.* They are farther apart, however, than in *L. nitida,* and their internal faces do not parallel each other vertically as in the latter species. The paramastoids are broad above and extend downward and considerably outward below the inferior edge of the bullæ, with which they are in contact for a part of their course. I fail to find this outward direction in the Yale specimens of the three species, in all of which they extend nearly directly downward. The outline of the facial vacuities is partially destroyed, but they were evidently relatively large.

The ramus is quite robust for a submature animal. The inferior border is very gently curved as in *L. decora,* and does not turn downward at the angle as in *L. major.* The coronoid process extends but slightly above the condyle, more as in *L. major,* and its superior edge does not curve backward, so pronounced a feature in *L. decora,* but not in *L. major.* I can not determine this character in *L. nitida.* The masseteric fossa is unusually deep, and the ramus very robust below the molar series. With respect to the occipital condyles, the external auditory meatus is situated much farther back than in *L. nitida,* but approximately as in *L. major* and *L. decora,* although relatively a little higher.

Measurements.

	mm.
Skull, length, occip. condyles to canine inc.	103
Bizygomatic diam.	82
Diam. of postorbital constriction	22.5

Max. width of brain-case	41
Width above P^2	31
Width between middle of orbits	37
Depth of malar below middle of orbits	15
Depth of paramastoid below inferior border of auditory meatus	29
Ant.-post. diam. of bulla	23.5
Transverse diam. of bulla	22.1
Ramus, depth, coronoid to angle	60
Depth below M_2	23
Total length from incisor border	92
M^1 plus M^2, length	24
Superior premolar series, length	28
M_1 plus M_2, length	23
Inferior premolar series, with P_1, length	27

Leptauchenia major Leidy 1856.

This species is represented in the Marsh Collection at Yale by a very well preserved skull with jaws, Cat. No. 10118, Y. P. M., as well as by other more or less fragmentary material, yielding data which have heretofore been undescribed.

Specific Characters.—The skull is intermediate in size between that of *Oreodon culbertsonii* and *O. gracilis.* The upper skull contour shows a steep forward declivity from the junction of the temporal ridges to the tip of the nasal bones, which lies above the line of the canines. The infra-orbital foramen is above the posterior part of P^3. The nasals are very narrow; the forehead is slightly elevated in the median plane and somewhat concave between that and the supra-orbital margins. The skull is depressed, especially in advance of the orbits. The temporal ridges diverge much more rapidly and widely than in *Oreodon.* The facial vacuities are large and extend posteriorly nearly to a line through the middle of the orbits. The muzzle is marked by a prominent ridge from the infra-orbital arch to the anterior end of the nasals. The palate is nearly flat. The bullæ are very much inflated and extend somewhat forward of the glenoid articular surface. The paroccipitals are broad, but tapering posteriorly and ending slightly below the inferior border of the bullæ. The latter are rather more roughly triangular, than oval, in outline, with the base posteriorly located.

The rami resemble those of *Oreodon* more closely than

do those of either *L. decora* or *L. nitida.* They are robust, nearly straight below the dental series, with a distinct downward trend at the angle. They are wide and moderately heavy below the coronoid and condyle.

The molar teeth are characterized by very heavy external styles, heavier than in any other of the species of this genus, and likewise heavier than in *Merychyus.*

Measurements.

(Cat. No. 10118, Y. P. M.)

	mm.
Skull, length, occip. condyles to canines, inc., approx.	139
Bizygomatic diam., approx.	100
Diam. of postorbital constriction	22.3
Max. diam. of brain-case	44
Width above P^2	31
Width between middle of orbits	46
Ant.-post. diam. of facial vacuity	34
Depth of malar below middle of orbits	23
Depth of paramastoid below inferior border of auditory meatus	28
Ant.-post. diam. of bulla	27
Transverse diam. of bulla	18.5
Ramus, depth, coronoid to angle	60
Depth below M_2	25
Total length from incisor border	113
Superior molar series, length	40
Superior premolar series, length	35
Inferior molar series, length	44
Inferior premolar series, with P_1, length	34

Leptauchenia nitida Leidy 1869.

This comparatively rare and little known species is represented in the Marsh Collection by several specimens collected on Pumpkin Creek, along White River, at Scott's Bluff, and near Fort Mitchell—all in Nebraska. Two skulls represent immature individuals, one of which is extremely delicate and fragile, with even the lower incisors preserved. Another skull, Cat. No. 10122, is that of a fully mature individual, and is remarkably well preserved. It lacks both rami and the incisor border, together with part of the zygomata.

Specific Characters.—This species is the smallest known in the genus. The muzzle is short and pointed; facial vacuities are smaller absolutely than in *L. decora,*

their posterior termination being but slightly back of the line of the anterior orbital margins; the forehead is slightly elevated along the sagittal plane and more prominently at the supra-orbital borders; the infra-orbital foramen is above the posterior edge of P^3; the face in advance of the orbits is quite narrow; the bullæ are very much inflated; the palate is nearly flat; the glenoid articular surface is much more convex downward than in *Oreodon;* there is a marked fossa at the anterior base of the postglenoid tubercle; this latter process is small and is composed apparently half of the squamosal and half of the tympanic bone, the dividing line in No. 10122 being a transverse vertical plane; the superior skull contour is a nearly straight gentle slope from the summit of the inion to the tip of the nasals; the bullæ are so greatly inflated that they are separated by an interval only 2 mm. in diameter; the frontals are produced between the nasal bones, which end in a wedge in the frontals.

The superior molars differ from those of the other species in that the size reduction from M^3 to M^1 is much greater, the antero-posterior diameter of M^1 being less than one half that of M^3. The hypocone of M^3 is quite small, while the metastyle is relatively large and prominent. The metacone is rotated inward more strongly than in *L. decora* or *L. major.* The premolars have a decided backward slope from root to crown, which does not occur in the Yale specimens of either of the other species.

Although No. 10122 is a robust specimen, I am inclined to believe that Leidy did not accurately estimate the length of the superior molars. He stated it to be 20 mm., and yet the length of M^1 plus M^2 in the type specimen is 13 mm. M^3 is lacking in the type. In all of the Yale specimens, the antero-posterior diameter of M^3 is more than 10 mm.

Measurements.

(Cat. No. 10122, Y. P. M.)

	mm.
Skull, length from occip. condyles to canines, inc.	95
Bizygomatic diam.	65
Diam. of postorbital constriction	21
Max. width of brain-case	36

	mm.
Width above P^2	24
Width between middle of orbits	30
Ant.-post. diam. of facial vacuity, approx.	21
Ant.-post. diam. of bulla	25
Transverse diam. of bulla	19
Depth of malar below middle of orbit	12.5
Superior dental series with canine, length	51
Superior molar series, length	25
Superior premolar series, length	20

Cyclopidius Cope 1878.

The generic distinctions between *Leptauchenia* and *Cyclopidius* are by no means clearly marked. Cope defined *Cyclopidius* as being "*Leptauchenia* without superior incisor teeth." As we now know the genus, this is an inconstant character. Some of the species had one or two superior incisors, and it is not unlikely that all of them possessed two. These, however, may have been, and probably were, in many cases very small and perhaps vestigial, so that they were easily lost or destroyed during the process of fossilization. The inferior incisors were likewise two in number. If we assume for the present at least that *Cyclopidius* had but two incisors in each tooth row, then we have the most marked generic distinction between this genus and *Leptauchenia,* which has the full complement of forty-four teeth.

Cyclopidius is found in a higher horizon than *Leptauchenia,* the latter being Upper Oligocene to Lower Miocene and the former being restricted to the Middle Miocene.

In general, it seems that *Cyclopidius* possesses, in an exaggerated form, the various peculiarities of *Leptauchenia.* The nasal vacuities are larger; the frontals are narrower and form but very little of the cranial roof; the zygomata are much heavier and more widespread; the cranium is very much narrower and smaller; the nasals are narrow bands which expand slightly at their junction with the premaxillaries; the external styles of the superior molars are more prominent; the inferior caniniform premolar is somewhat reduced, and, in size, more nearly approximates that of the true canine; the external auditory meatus is somewhat more posteriorly placed; the rami have become more robust and much heavier posteriorly, and the whole skull foreshortened and much more brachycephalic.

Pithecistes was established by Cope on a lower jaw in which, he said, P_1 and all of the incisors except I_3 had been lost. Likewise the true canine was no longer incisiform, but had again become caniniform. These characters were shown only in the type species, *P. brevifacies,* which was a very old individual. In 1899 Matthew showed that this genus was not valid. He wrote (p. 73):

"Careful comparison and more complete removal of the matrix show that: (1) the alveoli of two small incisors are present on each side; (2) the canine, mistaken by Cope for an incisor, is present and worn to a stump; (3) the first premolar, mistaken for canine by Cope, is present and caniniform; (4) there are no distinctions whatsoever from *Cyclopidius simus* except those due to age of the individual. *Pithecistes decedens* is the permanent and *P. heterodon* probably the milk dentition of a smaller species of *Cyclopidius;* both are founded on upper teeth."

I do not think it possible that in this family any form will be found in which P_1 has been lost and the true inferior canine become caniniform. This caniniform premolar has developed far in excess of the other premolars, and at the expense of the true canine, in all of the preceding genera of the Oreodontidæ. It is possible, however, that a form may be found without any incisors, either superior or inferior, a condition which has occurred in other groups.

Cyclopidius lullianus, sp. nov.

(Figs. 1-3.)

Holotype, Cat. No. 10117, Y. P. M. Spanish Mines, Wyoming. Lower Miocene (lower Harrison beds).

The type material consists of a skull and jaws, excellently preserved with the exception of the left zygoma and a portion of the left side of the cranium. It was collected in 1908 by Professor Richard S. Lull, after whom the species is named.

Specific Characters.—This is the largest species of the genus, and shows remarkably well the generic characters. Its specific peculiarities are very marked. The skull length is approximately that of a small *Oreodon culbertsonii.* The muzzle is short, and the zygomata much expanded. The nasal bones are very narrow, expanding anteriorly at the junction with the premaxillaries, which are small. The facial vacuities are very large. A shallow forward-facing depression represents the lacry-

Fig. 1.—*Cyclopidius lullianus*, sp. nov. Holotype. Lateral view of skull and jaw. Two-thirds nat. size.

Fig. 2.—*Cyclopidius lullianus*, sp. nov. Holotype. One half superior view of skull. Two-thirds nat. size.

10117, TYPE
Y. P. M.

Fig. 3.—*Cyclopidius lullianus*, sp. nov. Holotype. Anterior view of muzzle. Two-thirds nat. size.

mal fossa. The infra-orbital foramen is single and located above the middle of P^3. The frontals are much reduced and very narrow. A rather shallow but well marked depression separates the median sagittal ridge from the slightly elevated supra-orbital borders. The malar part of the zygoma is exceedingly thick and deep, while the squamosal portion is comparatively weak, except for the great expansion above the glenoid articular surface. The brain-case is relatively very small.

The rami are massive, deep, and heavy. The inferior border is much thickened and, below the anterior molar series, there is an osseous tubercle on each ramus. The position of this small tubercle is suggestive of that in the entelodonts, except that in the latter the size is very much greater. There are but two incisors in both dental series. This species is nearest to *C. brevifacies* Cope, but larger, and shows marked differences.

Measurements of Holotype.

	mm.
Skull, length, occip. condyles to prosthion, inc.	143.5
Bizygomatic diam.	104.5
Diam. of postorbital constriction	24
Max. width of brain-case	46
Width above P^2	40
Width between middle of orbits	60
Depth of malar below middle of orbits	28
Ant.-post. diam. of facial vacuities	47
Ramus, total length	131
Depth, coronoid to angle	88
Depth below M_2	35.5
Width below M_2	16.2
Superior dental series, with canine, length	78.2
Superior molar series, length	44.2
Superior premolar series, length	30.5
Inferior dental series, with P_1, length	70.5
Inferior molar series, length	40.5
Inferior premolar series, with P_1, length	27.5

Chelonocephalus schucherti, subgen. et sp. nov.

(Figs. 4-6.)

Holotype, Cat. No. 10123, Y. P. M. Middle Miocene, Badlands, near Hermosa, South Dakota.

The type material, which was collected in 1894 by H. F. Wells, consists of a well preserved skull, lacking the

occipital condyles and the incisor border. The individual is fully adult. The specific name is given in honor of Professor Charles Schuchert as a token of appreciation of his generosity to the Division of Vertebrate Paleontology, in the apportionment of funds.

This species resembles *Cyclopidius decedens* (*C. heterodon*) in two characters. Both species are smaller than *C. simus*, and both have the same antero-posterior diameter of P^4, but not the same transverse diameter. All the species of *Cyclopidius* are considerably larger than this and smaller than *Cyclopidius lullianus*, sp. nov. From other dimensions of *C. decedens*, it is apparent that this

Fig. 4.—*Chelonocephalus schucherti*, subgen. et sp. nov. Holotype. Lateral view of skull. Nat. size.

new species is not only smaller, but differently proportioned.

Distinctive Characters.—Great relative bizygomatic diameter, giving the skull a strong brachycephalic appearance. In fact, it is roughly circular in outline, superficially resembling that of the Chelonia. The zygomata are relatively heavy, although not very thick except near and at their origin above M^2 and the anterior part of M^3. The orbits look outward and upward. The sagittal crest is long and high, while the brain-case is relatively large. The sagittal crest is marked by a foramen produced by a spreading of the parietal bones, about on a line above the paramastoids. The frontals are narrow and the facial vacuities large. The basicranial area is foreshortened,

so that the much inflated bullæ lie below a part of the glenoid articular surface, and their anterior border is in advance of the glenoid surface. The small postglenoid

Fig. 5.—*Chelonocephalus schucherti*, subgen. et. sp. nov. Holotype. Superior view. Nat. size.

Fig. 6.—*Chelonocephalus schucherti*, subgen. et sp. nov. Holotype. One half palatal view. Nat. size.

processes are thin and plate-like, situated almost directly above the posterior margin of the bullæ. The bullæ are oval in outline, with their long diameter directed forward and inward at a slight angle. This foreshortening of the

ART. XXVIII.—*A Potamogeton from the Upper Cretaceous;* by EDWARD W. BERRY.

Since in some cases it is not practicable to determine fossil foliar remains conclusively, those cases in which this is possible merit emphasis lest they be buried in large systematic works on paleobotany and thus run the risk of escaping the attention of botanists and those authors who speculate on the existing distribution of plants while ignoring that of their ancestors.

The conclusive characters of the Potamogeton described in the present note merit calling attention to it in advance of my account of the associated flora, which may be long delayed. Relics of aquatic vegetation are generally much less durable than those of terrestrial forms and hence there is a relative paucity of such types in the geological record. Circumstantial evidence, as for example the delicate dental armature of Trachodon and other herbivorous dinosaurs, seemingly demands a soft plant food such as is furnished by aquatic plants, but the paleobotanist has but little to offer to the zoologist in answer to questions of this sort.

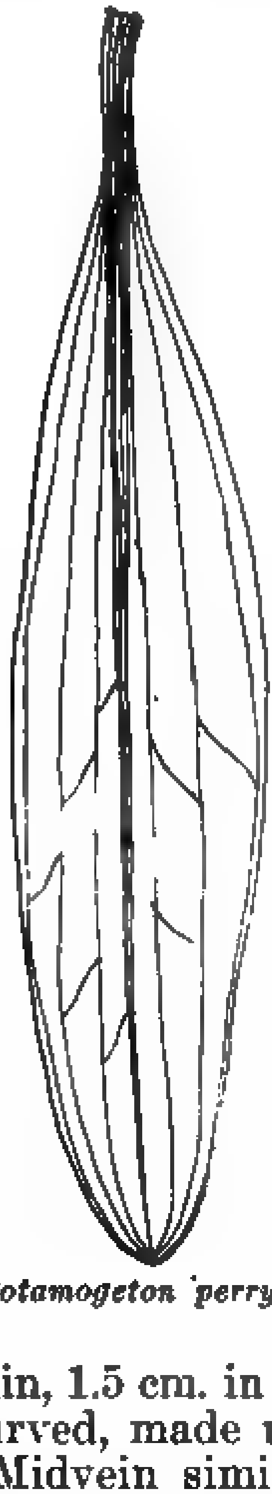
There is then a special interest attaching to aquatic fossil plants. In the very large American Upper Cretaceous floras the bulk of the fossils represent conifers and dicotyledonous leaves. Monocotyledons, aside from palms, are exceedingly rare, and this is usually considered as due to the imperfection of the record rather than as an actual portrayal of the true facts.

That the secondarily acquired aquatic adaptation in the angiosperms had already progressed a considerable distance before the close of the Upper Cretaceous is indicated by a number of rare forms found in deposits of estuary or lagoonal muds toward the upper part of the Mississippi embayment in Ripley time. These comprise the species of Potamogeton described below: A second species of Potamogeton, as yet undescribed since it may represent the submerged leaves of the former: a form referred to the genus Alismaphyllum: another that suggests the existing genus Hydrilla of the family Hydrocharitaceae: and a fifth of unknown identity, which is believed to have had the form and habit of Vallisneria, and to belong also to the Hydrocharitaceæ.

The new species of Potamogeton may be described as follows:

Potamogeton perryi sp. nov.

Leaves of relatively large size, elliptical to oblanceolate in general outline; with a rounded or emarginate apex and an abruptly or gradually narrowed base, decurrent on the broad flat petiole. Leaf substance thin, but firm and not membranous. Length ranging from 7 cm. to 10 cm. Maximum width ranging from 1.8 cm. to 2.6 cm.



FIGS. 1-3.—*Potamogeton perryi.* Natural size.

Petiole broad and thin, 1.5 cm. in length and about 3 mm. in width, slightly curved, made up of a row of parallel vascular bundles. Midvein similar to the petiole, i. e. broad and flat, not prominent, becoming much attenuated distad by the divergence of vascular bundles. Secondaries thin, immersed in the leaf substance, three or more acrodrome pairs, connected by thin oblique veinlets.

Named for the collector, Mr. E. S. Perry, who obtained it at the Perry Place in Henry County, Tennessee, from beds of Ripley age.

This is an exceedingly well-marked species and so modern in its facies as to be distinguished with difficulty from numerous existing species, such as the European *Potamogeton rufescens,* or the North American *Potamogeton nuttallii, alpinus, lonchitis,* and *lucens.* Two of these latter are also Old World forms, namely *P. alpinus* Balbis, and *P. lucens* Linné, and it is these two that are most similar to the fossil, particularly in the shortening of the petiole. Both are prevailingly pond rather than stream forms, and range on this continent from the Atlantic to the Pacific, and from Canada to Florida and Mexico in the case of *P. lucens,* although *P. alpinus* does not go so far to the southward.

Characteristic Cretaceous forms of Potamogeton are rare, and it would seem to be something more than a coincidence that several well-marked species appear in the geological record at about the same time in rather widely separated regions. These are, in addition to the present form, *Potamogeton cretaceous* Heer[1] from the Patoot beds of western Greenland—a form very similar to *P. perryi; Potamogeton middendorfensis* Berry[2] from the Middendorf arkose member of the Black Creek formation in South Carolina; and *Potamogeton ripleyensis* Berry[3] from the Ripley formation in western Tennessee.

Strangely enough the genus has not been authentically determined from Europe in strata earlier than the Oligocene, although allied forms occur in the Eocene of France. Nor are there any pre-Miocene records from Asia, the last due no doubt to the scarcity of known earlier plant beds on the latter continent.

There are upward of two score described fossil species, which are not uncommon throughout the Tertiary of the Northern Hemisphere. Many still existing species, represented by both leaves and fruits, appear in the Pleistocene records.

The existing species number more than three score, and they are present in both tropical and temperate regions, but are more varied in the latter. Most of the species

[1] Heer, O., Fl. Foss. Arct., vol. 7, p. 19, pl. 55, figs. 23, 24, 1883.
[2] Berry, E. W., U. S. Geol. Survey Prof. Paper 84, p. 27, pl. 4, fig. 6, 1914,
[3] In MS.

have an extended, and many a cosmopolitan range. Thus *Potamogeton perfoliatus* Linné extends over more than twenty degrees of latitude in North America and is found also in Europe and Asia.

All of the wide ranging forms extend into both high and low latitudes whereas species of restricted range are commonly confined to warm regions. Climate is less of a factor in aquatic than in terrestrial vegetation, but in spite of this it would appear that the glaciation of the Pleistocene in the lands of the Northern Hemisphere was one of the factors in extending the range of the present wide ranging forms, and that these are geologically older than those species of restricted range.

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ART. XXIX.—*Additional Notes on the Crystallography and Composition of Boulangerite;* by EARL V. SHANNON.[1]

Existing knowledge of the crystal form of boulangerite rests almost entirely upon the work of Sjögren[2] upon material from Sala, Sweden, which showed the composition of this mineral to be different from the formula usually given and endeavored to show its relation, both chemical and crystallographic, to diaphorite. The present writer has recently published a paper on the chemical composition of this mineral with 8 new analyses made upon material from various localities which apparently confirm Sjögren's conclusions relative to its composition.[3] Additional study of one of the specimens analyzed has shown the presence of measurable crystals which have been made the subject of the following notes. The exact history of the specimen is somewhat uncertain but it is known to be from the Wood River district in Blaine County, Idaho and it is probably from the Independence mine. An analysis of the material is given in the publication above cited. The crystals occur as small rosettes

[1] Published by permission of the Secretary of the Smithsonian Institution.
[2] Geol. Fören. Förhandl., **19**, 153-67, 1897.
[3] Proc. U. S. Nat. Mus., **58**, 589-598, 1920.

associated with pyrite and drusy quartz along a rift in a mass of white vein quartz containing disseminated pyrite crystals and fibrous masses of boulangerite. They reach a maximum length of about 1 millimeter, and are highly polished with metallic luster and light lead-gray color. They are all tabular parallel to the front pinacoid *a*(100) and seem to possess a distinct cleavage parallel to this plane. Several of the crystals were detached from the matrix and measured with a Goldschmidt 2-circle goniometer.

The crystals are all similar in habit, the dominant forms being the macropinacoid *a*(100), the prism *n*(120) and the pyramid *z*(124) while several other prismatic forms occur as narrow faces, the form and habit of the crystals being illustrated in fig. 1. The prism zone is strongly striated vertically.

The angles measured were found not to be in entire agreement with those given for the same forms by Sjögren and a question arose as to the advisability of substituting new axial values for this mineral. To this end the description of the mineral from the Swedish occurrence was carefully considered. The crystals from Sala, which seem to have been very minute, were obtained by dissolving the carbonate gangue with dilute hydrochloric acid. Although Sjögren states that the forms in the prism zone gave quite good angles, the crystals are said to have been strongly striated vertically and it seems probable that the quality of this zone on the present writer's crystals was fully as good as that on the crystal examined by Sjögren. He states clearly that the measurements recorded in his table were made on one and the same crystal on which the only terminal face was found, the dome *u*(012), upon which he bases his value for the *c* axis. This yielded only one measurement which was so poor as to be scarce usable at all. Five crystals from the Idaho occurrence were measured and on each of these the prism *n*(120) and the pyramid *z*(124) were present as distinct faces yielding good signals although the angles measured varied somewhat. By weighting each angular measurement according to quality the following average is obtained for the form *n*(120):

$$n\ (120) \qquad \phi = 44°23' \qquad \rho = 90°00'$$

while the pyramid *z*(124) gives the following average angles:

$$z\ (124) \qquad \phi = 44°47' \qquad \rho = 25°48'$$

Since the latter form yielded the better reflections its angles were taken as fundamental for calculating the crystallographic constants yielding the following:

$a = .5038$ $\log a = 9.70226$ $\log p_0 = 10.13386$ $p_0 = 1.3620$
$c = .6862$ $\log c = 9.83645$ $\log q_0 = 9.83645$ $q_0 = .6862$

The axial ratios thus derived may be compared with those given for boulangerite by Sjögren and those of diaphorite as follows:

	a : *b* : *c*
Boulangerite (new)	.5038 : 1 : .6862
Boulangerite (Sjögren)	.5527 : 1 : .7478
Diaphorite	.4919 : 1 : .7345

The crystals from Idaho show a well-defined cleavage parallel to *a*(100) while Sjögren does not mention any such cleavage in the material from Sala nor is such a pinacoidal cleavage given for diaphorite. The forms observed on the crystals from Idaho are given with their calculated and measured angles in the following table:

Forms and angles of boulangerite from Idaho.

		Measured		Calculated	
Letter	Miller	ϕ	ρ	ϕ	ρ
a	100	90°00′	90°00′	90°00′	90°00′
N	450	58°15′	90°00′	57°47′	90°00′
n	120	44°23′	90°00′	44°47′	90°00′
g	130	33°32′	90°00′	33°24′	90°00′
μ	140	27°50′	90°00′	26°22′	90°00′
k	180	13°33′	90°00′	13°55′	90°00′
r	210	75°13′	90°00′	75°51′	90°00′
t	310	79°44′	90°00′	80°28′	90°00′
?	5.12.0	38°11′	90°00′	39°34′	90°00′
z	124	44°47′	25°48′	44°47′	25°48′

Sjögren sought to show that boulangerite was the lead extreme of a series having the general composition expressed by the formula $5(Pb, Ag_2)S.2Sb_2S_3$ which is the formula which has been accepted for some years for diaphorite. In a recent paper Wherry and Foshag[4] have recognized the fact that lead and silver are not isomorphous in minerals of this type but that, when these bases of unlike valence occur in the same mineral, their ratio to each other is constant, the compound being essentially a double salt. This principle is futher discussed in a

[4] Wherry, E. T., and Foshag, W. F., Classification of the sulphosalt minerals, Jour. Wash. Acad. Sci., vol. 11, pp. 1-8, Jan., 1921.

paper by Foshag which is now in press. The formula assigned to diaphorite by these authors in $4PbS.3Ag_2S.3Sb_2S_3$ or with the ratio $RS:Sb_2S_3 = 7:3$. When this result was first submitted to the writer's attention it was thought possible that boulangerite might also have these ratios, the difference being small. The compositions to satisfy the two formulas are as follows:

	$5PbS.2Sb_2S_3$	$7PbS.3Sb_2S_3$.
Lead (Pb)	55.41%	54.01%
Antimony (Sb)	25.72	26.87
Sulphur (S)	18.87	19.12

An examination of the analyses published by the writer in the paper above cited shows that most of them agree most nearly with the first formula although one or two approach the second. The analysis of material from the specimen bearing the crystals here described agrees very closely with the 5:2 ratios which may not be significant as the analysis was made upon the fibrous portion of the specimen, the crystals not being sufficient in amount for analysis. The problem of determining the correct composition of boulangerite now seems further complicated by the probable existence of a lead sulphantimonite having 7:3 ratios. It is obvious that very exact analytical work on material of undoubted purity will be necessary to distinguish between these two compounds. Existing knowledge of the minerals diaphorite and boulangerite appears to indicate that they have different ratios of base to acid and hence fall in different groups, the crystallographic similarity being accidental and not significant. Any evidence as to the crystal form or physical properties of minerals of this general composition should be carefully recorded as such data may ultimately lead to the differentiation of two or more species.

Art. XXX.—*The Oriskany Sandstone Faunule at Oriskany Falls, New York;*[1] by Harry N. Eaton.

During the course of faunal studies of the Oriskany of central New York it seemed advisable to visit the type locality at Oriskany Falls whence the formational name was derived. As the result of several days' collecting in July, 1919 a faunule was found which is probably representative, and is enumerated below.

Extent and Stratigraphy.

The sandstone outcrops in a bold ledge on the hillside on the northern outskirts of the village of Oriskany Falls at an elevation of about 1080 feet. This hill is a plateau spur pointed southward, broadening out to the north in the southern part of Oneida County; bounded on the east by the valley of Oriskany Creek, and on the west by the valley of Sconondoa Creek. The outcrop is nearly unbroken for a mile northward of the village in the Oriskany Creek valley, and thence northward there are no further exposures owing to the drift cover. On the western side of the hill it can be traced by a line of bowlders, rising gradually to an altitude of 1260 feet to a point about 1¾ miles north of the village of Augusta, in harmony with the gentle southerly dip of the region. On account of the drift cover, the northern boundary of the formation is uncertain, but probably does not lie more than 3½ miles north of Oriskany Falls. The greatest breadth east and west is about 1¾ miles.

The thickness was given by Vanuxem[2] as "about twenty feet," but Brigham's[3] estimate of "about ten feet" is more in accord with the writer's measurements. Vanuxem's error was a natural one to make at the outcrop nearest the village, as at this place a row of large sandstone blocks has been plucked away from the parent ledge and moved a few feet downward so as to give the formation a double apparent thickness.

The Oriskany sandstone at this locality lies directly upon the Helderberg limestone,—or Manlius according

[1] The above paper was read before Section E, A. A. A. S., at St. Louis, Dec. 30, 1919. An abstract was published in Science, new ser., 51, 493, 1920.

[2] L. Vanuxem, Third Ann. Rept. Geol. Survey, Third Dist. N. Y., p. 273, 1839.

[3] A. P. Brigham, The Geology of Oneida County, Oneida Hist. Soc., Trans., 1887-1889, p. 109, 1889.

to Clarke,[4]—and is overlain by the Onondaga limestone. The friable nature of the rock is well known. The upper surface is more quartzitic and darker in color than the lower portions. Dr. Clarke[5] noted the abrupt transition here from the underlying limestone to the superjacent Oriskany sandstone, and spoke of its extent as follows:

"All calcareous beds are here wanting . . . This quality of rock does not occur in any of the eastward exposures of the Oriskany from Albany County to the New Jersey line except for an occasional thin streak without fossils. From Oriskany Falls westward no calcareous beds appear except toward the top of the deposit as the sedimentation grades into that of the Onondaga limestone above. . . .

"The character of the Oriskany deposit in New York from Schoharie County westward may be regarded in a general way as a series of arenaceous lenses (in strike section) connected by thin sheets of quartzitic sandstone. The outcrops at Oriskany Falls and Yawger's woods are such lenticular masses."

Fauna.

Vanuxem[6] lists four common Oriskany brachiopods as numerous in the lower part, and figures another brachiopod, also mentioning the occurrence of a pelecypod. Brigham[7] mentions *Spirifer arenosus* (Conrad) and *Rensselæria ovoides* (Eaton) as being abundant. Both authors note the occurrence of the fossils as interior casts. Clarke[8] lists *Chonostrophia complanata* (Hall), although this species was not found by the writer. The following is the list of species disclosed by the present study:

Spirifer arenosus (Conrad), *S. murchisoni* Castelnau, *Rensselaeria ovoides* (Eaton), *R. ovoides* (Eaton), var. nov.?, *Hipparionyx proximus* Vanuxem, *Meristella lata* (Hall), *M. laevis* (Vanuxem), *Eatonia peculiaris* (Conrad), *Centronella glansfagea* (Hall), *Leptostrophia* (*Stropheodonta*) *magnifica* (Hall) ?, *Rhipidomella emarginata* (Hall), *Megalanteris ovalis* Hall?, *Modiomorpha* sp. undet., *Actinopteria* sp. undet., and *Diaphorostoma ventricosum* (Conrad).

Rensselæria ovoides is a common fossil in the main outcrops and boulders. The possible new variety of this

[4] J. M. Clarke, The Oriskany Fauna of Becraft Mountain, Columbia County, N. Y., N. Y. State Museum, Memoir No. 3, p. 78, 1900.

[5] Op cit., p. 78.

[6] L. Vanuxem, Geol. N. Y., part 3, Survey Third Dist., pp. 123-125, 1842.

[7] Op. cit., p. 109.

[8] Op. cit., p. 78.

species has been previously found by the writer at Yawger's Woods, near Union Springs, New York, and its description will be published later. The shell shows possible resorption on the free margin, and is abbreviated accordingly. This fossil is quite similar in appearance to *Meristella lata* and may have been confused with the latter form by Vanuxem.[9] It is the most abundant form.

Spirifer arenosus is very abundant, occurring with shell markings preserved and also as interior casts.

Spirifer murchisoni is less common than *S. arenosus*.

Hipparionyx proximus is not common, and occurs near the top of the formation where the rock is quartzitic, the rotund dorsal valve usually being preserved.

Centronella and *Rhipidomella* are rare.

The identifications of *Leptostrophia* and *Megalanteris* are doubtful and in each case rest upon the interpretation of single specimens.

It is interesting to note that few, if any, of the type specimens of the Oriskany fauna in the state museum at Albany are from Oriskany Falls, showing in what light esteem the early collectors held the Oriskany Falls occurrence.

Correlation.

While correlations may be premature due to the paucity of species, certain comparisons may be of value. *Meristella lævis* is an Helderbergian and Lower Oriskany form. *Centronella glansfagea* is common in the Upper Oriskany and occurs in the Onondaga. It is also plentiful at Yawger's Woods, near Union Springs. *Rhipidomella emarginata* is known in the Helderbergian but has not been reported previously from the Oriskany. (This last statement is based on the probability of *R. emarginata* being a separate and distinct species, as distinguished by the Maryland Survey, and not merely a variety of *R. oblata.*)

Of the ten species identified beyond doubt, 80 per cent is found in Schuchert's[10] list of Lower Oriskany species, and an equal number appears in his Upper Oriskany list. Dr. Schuchert[11] regarded the faunule as of Upper Oriskany age from the small assemblage of fossils reported

[9] Op. cit., p. 125, 1842.

[10] C. Schuchert, Lower Devonic Aspect of the Lower Helderberg and Oriskany Formations, Bull., Geol. Soc. America, 11, 292-296, 1900.

[11] Op. cit., p. 301.

by Vanuxem. Stauffer's[12] list of the Oriskany fossils of Ontario contains 70 per cent. The writer has found all of them at Yawger's Woods.

Acknowledgments.

Dr. G. D. Harris of Cornell University and Prof. E. R. Smith of Oberlin College assisted in identification of species, and Prof. H. O. Whitnall of Colgate University supplied field data in connection with the preparation of the foregoing paper. Dr. J. M. Clarke has kindly read the manuscript. Acknowledgment of this help, freely given, is hereby gratefully made.

Department of Geology,
Syracuse University.

[12] C. R. Stauffer, The Devonian of Southwestern Ontario, Geol. Survey Canada, Mem. 34, 249-251, 1915.

Art. XXXI.—*Two Petrified Palms from Interior North America;* by Neil E. Stevens.

The discovery of calcified palm trunks in the upper Pierre Cretaceous of South Dakota was announced in 1903 by Wieland.[1] The discovery of any plants with structure conserved in marine horizons is notable. Moreover palm wood of undoubted Cretaceous age has been reported only a few times in North America, and with the exception of *Palmoxylon Cliffwoodensis* Berry[2] the species are all from more recent horizons than the Pierre. An uncommon interest, however, attaches to these Pierre palms because of association in a remarkable assemblage of land and marine forms. In a paper discussing the marine turtle *Archelon* Wieland says:

With *Archelon ischyros* and *Marshii* there occurs in the uppermost 100 feet of the Fort Pierre (No. 4 Upper Cretaceous), as developed on the Cheyenne River, a series of immediately associated forms of more than ordinary interest. In the first place, I have obtained in this same horizon well preserved toe bones of a Dinosaurian nearly of the form and nearly as large as those of *Claosaurus annectens,* which I shall figure later as *Claosaurus* (?) *affinis* sp. nov. And presumably from the same drift from a not far distant shore, I secured an exquisitely preserved new species of Palm stem, later to be described as *Palmoxylon cheyennense.*

Secondly, associated with these land forms are numerous [Plesiosaurs], a shark (a broad-toothed *Lamma*), a fish allied to *Beryx,* a Saurocephalodont, and the following invertebrates.—*Nautilus De Kayi* (very abundant in the matrix of one of the large turtle skeletons), *Placenticeras placenta, Scaphites nodosus, Emperoceras Beecheri* Hyatt, *Baculites ovatus* and *compressus* Say, *Callista Deweyi* M. and H., *Inoceramus,* etc., etc.

Regarding the discovery and age of the petrified palm trunks, Wieland, the only person who has thus far observed them afield, makes the further statement for publication here:

The great turtles, the Dinosaur, Plesiosaurs, the invertebrates and the palms, could, in fact, be observed within a radius of one mile. The palms are found on both sides of the South Fork of the Cheyenne where the Oligocene overlap is most deeply cut, to the east of the Black Hills, in the region of the cañon-like "draws" of the bad lands, know as the "Quinn," "Battle Creek," and the "Corral Draw." They have been found four

[1] Wieland, G. R., this Journal (4) vol. 15, pp. 211-216. 1903.
[2] Berry, E. W., this Journal (4) vol. 41, pp. 193-197. 1916.

times, and always in surroundings indicating the Pierre. From at least one occurrence of these palm stems it was evident that transportation for a long distance from the overlying Oligocene was not possible. I hold them as certainly Cretaceous.

The sections of palm wood cut by Wieland at the time of his original publication were in 1920 turned over to me for further study, and from them the accompanying figures have been made.

For convenience in comparison there is included in the present paper a description of a species of palm wood from the lower portion of the Denver formation (Eocene). The specimen upon which this species is based forms part of a large collection of Palmoxylon material obtained by Dr. George L. Cannon of Denver, and with other representative material from the same collection has been presented by him to the Yale Museum. Dr. Cannon's collection of petrified palm stems is the most notable thus far brought together in North America and deserves full monographic treatment. The sections of the Denver palm were prepared at the U. S. National Museum through the courtesy of Dr. George P. Merrill.

Palmoxylon cheyennense Wieland

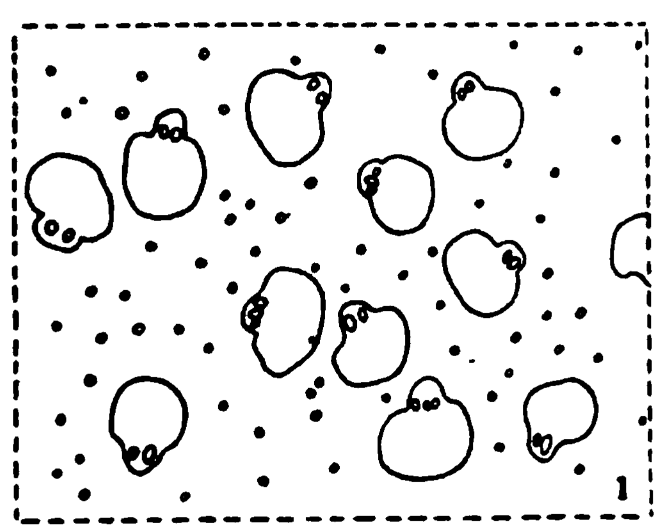
The palm stems of the Cheyenne have not been traced back to material *in situ* thus far. So that only the eroded stem centers are at hand. These are found as more or less spindle-shaped forms several feet in length by four or five inches in diameter. Being calcified, the sections must be ground with some care.

Structure.—Although the preservation is so excellent, and the sections carefully made, the wood of *P. cheyennense* appears dense in cross section. This is due to the large size and relatively compact arrangement of the fibrovascular bundles (cf. figs. 1 and 2), to the presence of numerous bast strands between these bundles, and to the absence of large intercellular spaces among the cells of the fundamental tissue.

The cells of the fundamental tissue present no unusual features. They are variable in size and shape, and are closely packed, with few or no intercellular spaces. No pitting is evident in their walls, and there are no specially thickened or differentiated cells. The auxiliary sclerenchyma bundles, rather regularly scattered among the

fibrovascular bundles, are usually about 50 μ to 75 μ in diameter, and show from 15 to 30 cells in cross section.

Fibrovascular bundles.—The fibrovascular bundles are rather close together, in the sections examined, and vary from about 20 per sq. cm. to about 35 per sq. cm. (cf. figs. 1 and 2). The bundles themselves are rather large, usually measuring at least 1 mm in shortest diameter, by 1 to 1.5 mm in longest diameter, as compared, for example, with .6 to .75 mm. by 1 mm. in *P. anchorus* Stevens of the New Jersey Cretaceous, and .5 mm. by 1 mm. in *P. Cliff-*



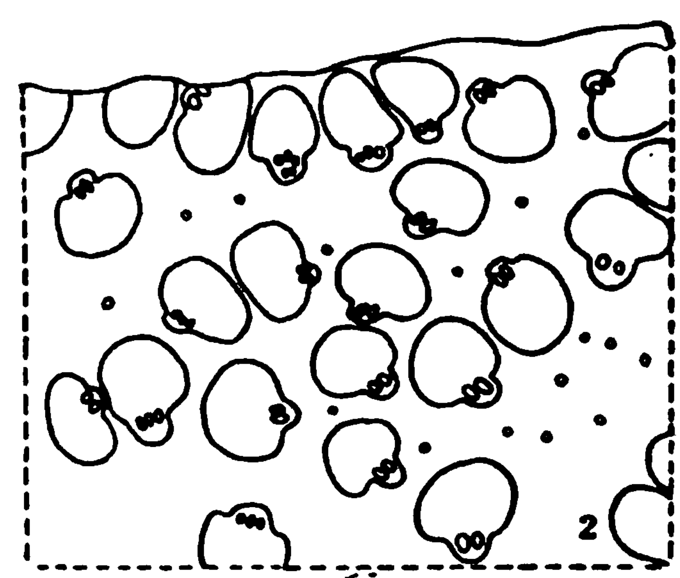


Fig. 1.—*P. cheyennense*, outline showing relative size and arrangement of the fibrovascular bundles in the interior portion of the stem. X 5.

Fig. 2.—*P. cheyennense*, outline showing relative size and arrangement of the bundles in the outer portion of the stem. X 5.

woodensis Berry. In the material studied the bundles were chiefly of the "longitudinal" type, that is, typical upright stem bundles with two, or sometimes three large vessels, .133 mm. to .055 mm. in diameter (fig. 3). In the phloem, which is preserved in a few of the bundles, twelve to twenty sieve tubes may be distinguished. The sclerenchyma portions, which are composed of typical bast fibres closely appressed, vary in shape but are predominantly ovoid and rather regular in outline. As is best shown in longitudinal section (fig. 5) a band of sclerenchyma fibers occurs on the side of the vessels opposite the phloem. This is the so called posterior sclerenchymous arch of Stenzel.[3]

On one slide, that from which figure 2 was made, there occur nine or ten bundles of the type shown in figs. 4, 6, and 7. These are obviously either the "Ubergangs-

[3] Stenzel, K. G., Fossile Palmenhölzer, Beiträge zur Paläontologie und Geologie Österreich—Ungarns und des Orients, Band XVI, Heft IV, p. 1-182, 1904.

Fig. 3.—*P. cheyennense*, a longitudinal bundle showing three large vessels. This bundle is slightly smaller than many of those shown in the sections, and the phloem is well preserved. A single bast strand is also shown. X 45.

X 45.

bündel" or the "Kreuzungsbündel" of Stenzel. It is not always easy to decide in which class a given section of a bundle should be placed; nor is the distinction of great importance, since the two names are used to designate merely different regions of the same bundle. The "transition bundle" is simply the longitudinal bundle as it turns outward toward a leaf, while the "transverse bundle" (which might well be called "oblique") is the continuation of the transition bundle out toward a leaf.

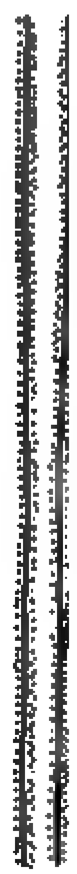


Fig. 5.—*P. cheyennense*, longitudinal section of a fibrovascular bundle, showing (left to right) parenchymatous cells of fundamental tissue, sclerenchyma (the posterior sclerenchymous arch), two vessels, phloem region (not preserved), a portion of the main bast region, and more fundamental tissue. X 45.

Probably the section shown in fig. 4 most nearly exemplifies Stenzel's description of a transition bundle, and figs. 6 and 7 the oblique bundle.

One curious bundle was found, fig. 8, which might be interpreted as a chance union of two bundles, or possibly as a branching longitudinal bundle.

Fungus hyphæ.—Fungus hyphæ are apparently common in petrified palm woods. Berry has described two

species[4] (*Peronosporoides palmi* and *Cladosporites oligocaenicum*) in *Palmoxylon cellulosum* Knowlton. The writer found fungus hyphæ in *Palmoxylon anchorus*[5] and published some notes as to the apparent effect of the fungus on the wood. Hyphæ are also abundant in certain parts of both species discussed in this paper. In *P.*

Figs. 6 and 7.—*P. cheyennense,* oblique bundles. X 45.

cheyennense occur hyphæ of two distinct types. Some are fine and without evident septations; others, much

[4] Berry, E. W., Remarkable Fossil Fungi. Mycologia 8, pp. 73-78. 1916.
[5] Stevens, N. E., this Journal (4), vol. 34, pp. 421-436, 1912.

larger, sometimes as much as 16 μ in diameter, are septate, and have taken on a dark color. From fig. 9 it is evident

Fig. 8.—*P. cheyennense*, double bundle. X 45.

Fig. 9.—Fungus hypha in *P. cheyennense*, the hypha apparently penetrates to, but not into, the bast cells. X 80.

that these larger hyphæ grow for considerable distances within the parenchymatous cells of the fundamental

tissue, though able to penetrate the walls of those cells. Fig. 10 shows the constriction in a hypha where it passes through the wall of a host cell, a condition which has often been observed and figured from living material.

As in other fossil palm woods the hyphæ are most abundant in the cells of the fundamental tissue and in the vascular elements, particularly the phloem, of the fibro-vascular bundles. No hyphæ appear in or among the bast cells although repeatedly occurring in close proximity to them, fig. 9. That the fundamental tissue should be

Fig. 10.—Photomicrograph of fungus hypa penetrating wall of cell of *P. cheyennense.*

attacked by the fungus while the bast regions of the bundles remain unchanged is quite in accord with the present action of fungi on the palms. In partly rotted palm logs recently noted in Southern California the fundamental tissue was almost entirely broken down, yet the bast portions of the bundles were tough and morphologically apparently unchanged. This close resemblance of fossil and modern fungi in method of attack on the host may well be considered as indicating that the environment of a fungus growing inside the stem of a palm was relatively the same ten million years ago as it is today.

Description of Species.

Palmoxylon cheyennense Wieland.

Locality,—Pierre, Upper Cretaceous, near the Cheyenne River south of mouth of Battle Creek, South Dakota.

Type in Yale Museum.

Fibrovascular bundles more numerous near the periphery of the stem (about 35 per. sq. cm.) than internally (about 20 per sq. cm.), about 1 mm. in shortest diameter by 1 to 1.5 in longest diameter, somewhat variable in size and shape, chiefly regular in outline. "Posterior sclerenchymous arch" present. Auxiliary sclerenchyma bundles numerous. Fundamental tissue of stem without intercellular spaces or conspicuously thickened

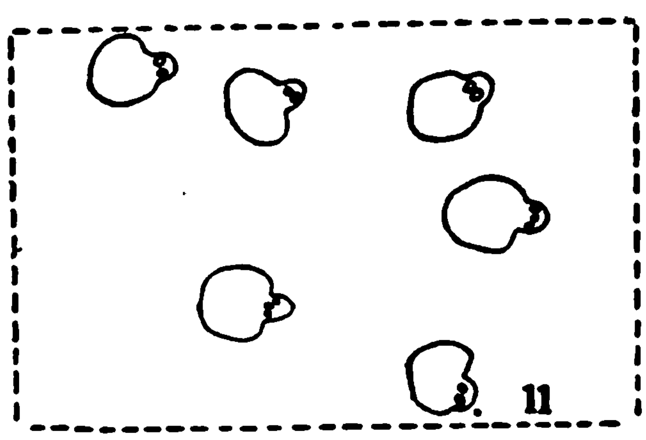


Fig. 11.—*Palmoxylon cannoni*, outline showing relative size and arrangement of the fibrovascular bundles of the stem. X 5.

or pitted cells. The bast portion of the fibrovascular bundles much larger than the vascular portion.

The Denver Specimen.

The palm wood here selected for comparison with *P. cheyennense* occurs as a silicified black mass from near the base of a large stem. In general appearance this black and dense specimen suggests some meteorite of a hundred or more pounds. The structure appears in remarkable detail, only the phloem (which indeed may have been destroyed before silicification) failing of preservation.

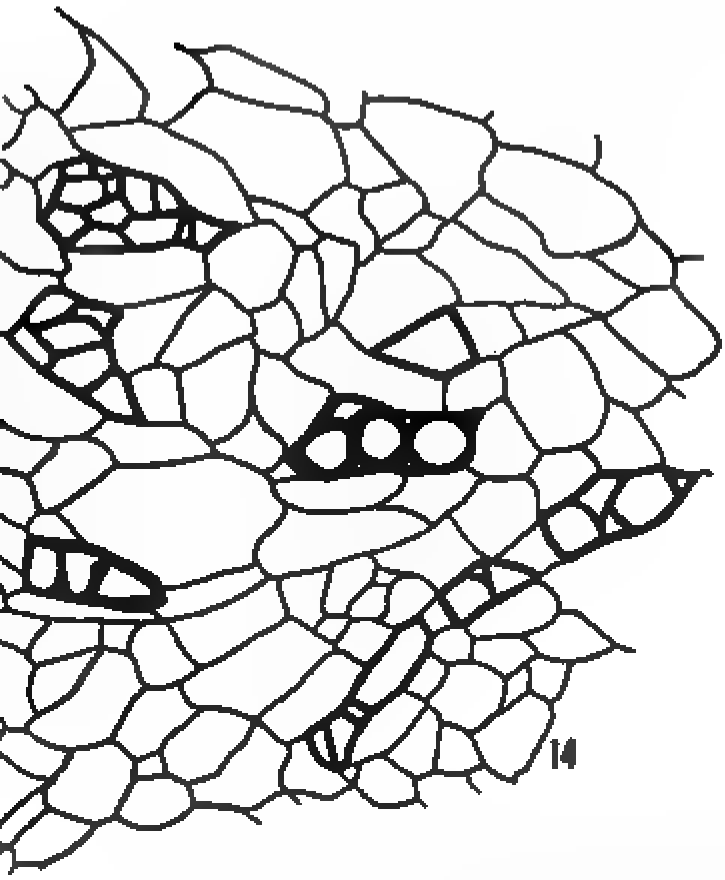
In contrast to *P. cheyennense* the wood of the Denver specimen has the fibrovascular bundles rather widely separated, (fig. 11) only about ten per sq. cm. Typical longitudinal bundles (fig. 12) measure from .8 to 1. mm. by .9 to 1. mm. in diameter and contain characteristically two large thick walled vessels, usually from .166 to .100 mm. in diameter. The sclerenchyma portion is rounded

Fig. 12.—*P. cannoni*, typical longitudinal bundle showing two large vessels. The phloem was not preserved. X 45.

Fig. 13.—*P. cannoni*, transition bundle showing two large and several small vessels. X 45.

in cross section and flattened where it joins the vascular portion. The phloem elements were nowhere preserved. Most of the bundles in the sections so far cut are of transition regions, one of which is shown in fig. 13.

The fundamental tissue of this species is rather specialized. Like that of *P. cellulosum* Knowlton it has large intercellular spaces (fig. 15) but scattered among the typical parenchymatous cells, usually in groups of three to ten, are much thicker "stone" cells (fig. 14). These



14

Fig. 14.—*P. cannoni*, portion of the fundamental tissue which contains many stone cells (thick walled) among the typical parenchymatous cells (thinner walled); several intercellular spaces are also shown. X 45.

Fig. 15.—*P. cannoni*, portion of the fundamental tissue close to that shown in figure 14, but containing no stone cells. In this figure the cells are outlined in stipple so that the large intercellular spaces are readily distinguished. X 45.

stone cells vary considerably in size, in number associated in a single group, and thickness of walls, while some seem to be pitted.

Of hitherto described species the one under consideration seems most closely to resemble *P. remotum* Stenzel from the Oligocene[6] near Washington, Mississippi. Like

[6] Berry, E. W. The Flora of the Catahoula Sandstone, in Shorter contributions to general geology. U. S. Geol. Survey, Prof. Paper 98., pp. 227 to 252, 1917.

P. remotum its vascular bundles are scattered, rather rounded in outline, and the fundamental tissue contains thick walled cells (dark colored in the fossil material). These thick walled cells of the fundamental tissue differ markedly from the similarly placed "dark cells" distinguished by Stenzel (3, p. 197) in *P. porosum* and *P. remotum* in that they usually occur in groups, have larger cell cavities, and are variable in size and shape. The stone cells thus constitute a good diagnostic character of the species (fig. 16.)

The present species of silicified palm wood can appropriately be named only after its finder, Dr. George L. Cannon, who has done so much to advance the knowledge of both the fossils and the geology of the Denver region.

Fig. 16.—*P. cannoni*, stone cells showing their varying size and wall thickness. One cell shows pits in the lower wall. X 80.

Description of Species.

Palmoxylon cannoni, sp. nov.

Locality—Lower portion of the Denver formation (Eocene) western suburbs of Denver, Colorado.

Type (portion of specimen and the type sections) in Yale museum.

Fibrovascular bundles scattered, usually about 10 per sq. cm., .8 to 1. mm. in diameter. Bast region rounded in outline, flattened where it joins the vascular portion. No marked difference in size, shape or arrangement of fibrovascular bundles in different parts of the specimen. No auxiliary sclerenchyma bundles. Fundamental tissue composed of irregular, rather thin walled cells, with large intercellular spaces, and also beset by groups of thicker walled "stone" cells varying greatly in size, thickness of wall, and number of cells to the group. Stone cell groups usually measure from .1 to .3 mm. in diameter.

Classification.

In the present state of knowledge regarding the anatomy of fossil, and living, palms the investigator may well adopt the system used by Stenzel (3) which is the result of the most extensive study of the anatomy of fossil palms yet published. Like all artificial systems it presents some difficulties in application. For example, when the writer described *P. anchorus* he was inclined to place it in Stenzel's class C, "Kokos-like stems," because no marked difference in size, shape or arrangement of the inner and outer bundles was detected. The bundles in this species are, however, much too far apart to agree with the "Kokos-like stems." Again, *P. anchorus* might well be placed in the subdivision Lacunosa of Stenzel's group Complanata, which includes species with the fibrovascular bundles separated from one another by more than one diameter. But so doing involves the assumption that in the extreme outer portion of the stem, lacking in the specimen, the fibrovascular bundles were close together, this being a distinguishing character of Stenzel's Class B. "Corypha-like stems."

The two species considered here fit easily into Stenzel's scheme. In *P. cheyennense* both peripheral and more central bundles have the sclerenchyma portion much larger than the vascular portion, which together with the fact that the central bundles are more widely separated than the peripheral places it among the "Corypha-like stems." The shape of the sclerenchyma portion, which is flattened where it joins the vascular portion, places it in Group IV, "Complanata," and the close arrangement of its fibrovascular bundles and its dense fundamental tissue indicate that it belongs to the sub-group "Solida."

P. cannoni also apparently belongs to the group "Complanata" but to the sub-group "Lacunosa" because the fibrovascular bundles are more than one diameter apart, and the fundamental tissue has large intercellular spaces. Among species belonging to this sub-group it most nearly resembles *P. remotum* in the arrangement of its fibrovascular bundles and in the presence of thick walled cells scattered among the cells of the fundamental tissue. The vascular portion of the bundle in *P. remotum* is, however, much larger as compared to the sclerenchyma portion, than in *P. cannoni*.

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ART. XXXII.—*The Isomorphic Relations of the Sulphosalts of Lead and Copper;* by WILLIAM F. FOSHAG.[1]

The sulphosalt minerals are chiefly compounds of lead, silver and copper with sulphur and antimony, arsenic and bismuth. Rarely iron, zinc, mercury, thallium and manganese enter into the composition of these minerals to any considerable extent, while selenium and tellurium may replace some of the sulphur. In these compounds sulphur, selenium and tellurium are strictly isomorphous, as are also antimony, arsenic and bismuth. A critical survey of all reliable data, however, indicates that the lead, and silver and copper are not isomorphous and that the formation of mixed crystals does not take place. This fact does not seem to have been generally recognized and our standard text-books contain formulas of the type $(Pb,Ag_2)_5Sb_4S_{11}$ (diaphorite) and $(Cu,Pb)_3Sb_2S_6$ (bournonite). We find, where the analyses are reliable, that the silver minerals, pyrargyrite, stephanite, etc., are remarkably free of lead and that the lead minerals rathite, sartorite, etc. are free of copper and silver. H. Rose was the first to state this fact. He says,[2] "I have never seen lead sulphide occurring together with the other metallic sulphides except copper sulphide and sometimes with iron sulphide, which, however, are in such small amounts that they do not appear to belong to the compound. The compounds that do not contain lead sulphide are completely free of lead even when they are surrounded by galena or the crystals rest upon galena."

These deductions of Rose seem to have received little attention other than occasional denial in the early literature. We shall see that his generalization is correct except for a certain type of compound.

In order to determine whether there is considerable miscibility between lead on the one hand and silver and copper on the other the writer undertook to collect a number of analyses of the sulphosalts, noting the kind of material upon which the analyses were made. Unfortunately the descriptions of the material analyzed were in

[1] Published by permission of the Director of the Smithsonian Institution.
[2] Ueber die in der Natur vorkommenden nicht oxydirten Verbindungen des Antimons und des Arseniks, Pogg. Ann., 15, p. 469.

almost all cases hardly adequate to determine how free of admixture the particular sample was. Only in a few cases were any mineralographic examinations attempted and these invariably showed small amounts of admixture even where crystals were used. In many cases copper and silver have not been determined in lead salts or lead sought for in copper or silver salts. The sums, however, indicate that their amounts, if present at all, are negligible. Because of this unsatisfactory character of the analyses they are not included here and only the general results will be noted. Of 32 analyses of lead minerals, made mainly upon crystallized material and embracing all the species, none showed a copper or silver content of over 1 percent and in most cases hardly more that 0.5 percent. Of 21 copper salts only one showed a percentage of more than 1 percent of lead. Of the silver salts two analyses from the same locality made upon "excellent" material showed over 1 percent of lead. Twenty-three showed less than 1 percent or none at all. These analyses were picked only to the extent that the material was crystallized or apparently homogenous as far as determinable.

It is evident that the miscibility between lead on the one hand and silver and copper on the other is very slight if it takes place at all. It is difficult to determine from the existing analyses whether the small amounts of lead, or of the silver and copper, are due to slight miscibility or to admixture. Since mineralographic examination has shown the presence of foreign material even in the best crystallized samples it is safe to assume that the small percent of these constituents are foreign to the mineral proper.

We have another type of compound in which lead, silver and copper do occur together in considerable amounts. These include such minerals as diaphorite, bournonite, freieslebenite, etc. A survey of the analyses of these minerals shows them to have a remarkably constant composition. They are in fact *double salts*. In some cases the minerals have been recognized as double salts, in some this has been suggested, but in a large number of cases they are regarded as isomorphous mixtures. In all cases the ratios of the constituent sulphides to each other are simple and definite. These minerals are as follows:

Andorite	$AgPbSb_3S_6$	$Ag_2S{\cdot}2PbS{\cdot}3Sb_2S_3$
Alaskaite	$Ag_2Pb\ Bi_4S_8$	$Ag_2S{\cdot}PbS{\cdot}2Bi_2S_3$
Schirmerite	$Ag_4PbBi_4S_9$	$2Ag_2S{\cdot}PbS{\cdot}2Bi_2S_3$
Owyheeite	$Ag_2Pb_5Sb_6S_{15}$	$Ag_2S{\cdot}5PbS{\cdot}3Sb_2S_3$
Brongniardtite	$Ag_2Pb\ Sb_2S_5$	$Ag_2S{\cdot}PbS{\cdot}Sb_2S_3$
Schapbachite	$Ag_2PbBi_2S_5$	$Ag_2S{\cdot}PbS{\cdot}Bi_2S_3$
Freieslebenite	$Ag_3Pb_2Sb_3S_8$	$3Ag_2S{\cdot}4PbS{\cdot}3Sb_2S_3$
Diaphorite	$Ag_3Pb_2Sb_3S_8$	$3Ag_2S{\cdot}4PbS{\cdot}3Sb_2S_3$
Seligmanite	$CuPbAsS_3$	$Cu_2S{\cdot}2PbS{\cdot}As_2S_3$
Bournonite	$CuPbSbS_3$	$Cu_2S{\cdot}2PbS{\cdot}Sb_2S_3$
Aikinite	$CuPbBiS_3$	$Cu_2S{\cdot}2PbS{\cdot}Bi_2S_3$

The above formulas show the simple ratios of the constituent sulphides. This, together with the constancy of composition, even in specimens from widely differing localities and occurrences, places these minerals definitely as double salts.

There are no simple silver analogues of the lead salts. Where a silver-bearing mineral falls into a group with a number of lead minerals it is one of the double compounds given above.[3] In the case of the copper salts there are a few cases in which they are similar to the lead salts in type of compound but there seems to be evidence that they also are not isomorphous.

The conclusions arrived at from a critical survey of the best analytical data are: (1) that lead on the one hand and silver and copper on the other hand are not isomorphous and that they do not form mixed crystals; (2) that the silver-lead or the copper-lead sulphosalts are double salts.

[3] See Wherry and Foshag, A new Classification of the sulfo-salt Minerals, Jour. Wash. Acad. Sci. 11, 1, 1921.

ART. XXXIII.—*The Occurrence of Calcareous Sandstone in the Recent Delta of Fraser River, British Columbia, Canada ;* by W. A. JOHNSTON.

The occurrence of calcareous sandstone, which is apparently forming in the Recent delta of Fraser river, British Columbia, was brought to the attention of the Geological Survey, Canada, by samples sent in by Mr. W. P. Gross, Engineer of the Department of Public Works, in charge of dredging on Fraser river. The occurrence was examined during the course of an investigation, made during parts of 1919 and 1920, of the characteristics of Fraser river and its delta, and, because of its rarity and unusual character, is here described.

The Recent or modern delta of the Fraser river is building out into fairly deep water in the Strait of Georgia. The delta extends inland for 19 miles and across its seaward front is 14 miles wide. The surface of the delta is practically all below the level of high tide, and the delta land high enough to be reclaimed is diked. Sand banks, exposed in large part at low tide but completely submerged at high tide, form the seaward part of the delta and extend on an average 4 to 5 miles from the higher delta land. A number of distributaries flow through the delta, the main Fraser flowing the central part, the North Arm along the northern side of the delta, and in the southern part a number of smaller outlet channels occur.

The calcareous sandstone occurs in the sand banks in the seaward part of the delta. It was dredged by the Government dredge near the inner end of the entrance of the North Arm of the Fraser, where a bar was cut through and large quantities of the material thrown out. It was also dredged by the Government dredge and by the writer in the main channel of the river in its seaward part, and by the writer in the seaward part of the old channel of the river south of the present main channel. It is known to the fishermen, who refer to it as "clinkers" and state that it frequently fouls their nets in the channels on the sand banks both north and south of the main outlet channel of the river. It probably does not form in the river channels but in the sand banks, and occurs in loose masses in the channels because of erosion of the sand

[1] Published by permission of the Director of the Geological Survey, Canada.

banks and shifting of the river channels; for the material dredged from the bottom of the river is usually waterworn, whereas that dredged from the sand banks is not, and the currents in the channels are too strong to permit of formation of the material. A careful search of the sand banks exposed at low tide failed to reveal any of the sandstone in place. It probably, therefore, forms below the level of low tide but at a depth of only a few feet below that level. It can not possibly be derived from erosion of older formations for no such deposits are being eroded by the river, and it occurs in the seaward part of the Recent delta to which no material larger than fine gravel is being transported by the river.

The specimens of the material obtained show that it consists in part of sandstone of which the cementing material is calcium carbonate, in part of sandy or silty and shelly limestone, and in part of concretionary limestone. A partial analysis of one sample of the material, made by Mr. R. D. McLellan of the Department of Mines, Canada, gave the following results:

SiO_2	42.01	per cent.
$Fe_2O_3 + Al_2O_3$	7.42	" "
CaO	36.04	" "
CO_2	14.40	" "
H_2O	0.02	" "
Total	99.89	per cent.

The material of this specimen is composed of sand grains cemented together by calcium carbonate, which constitutes 50 per cent of the rock. The proportion of lime varies considerably in different specimens, the concretion-like specimens being largely composed of lime; others are composed largely of shells with a mixture of sand and silt cemented by lime. The material is largely calcareous sandstone. It occurs as irregularly shaped masses which are quite consolidated when brought out of the water. Marine shells partly dissolved and fragments of wood only slightly altered are nearly always associated with the occurrences and usually form parts of the material. In the vicinity, where the material occurs there is usually an escape of gas which is inflammable and is probably marsh gas. During the freshet stage of the river, (May, June, and July,) the sand banks are covered for the greater part of the time by fresh river water. During the low-water stage sea-water covers the banks

most of the time. At certain stages of the river, particularly during the times intermediate between high and low-water stages of the river, there are daily oscillations of sea-water and river-water over the banks, because of the tides. During the greater part of the year, therefore, the sand banks are saturated with sea-water and during the freshet months they are saturated with river-water. The river-water during the freshet is 2 to 4 degrees C. warmer than the sea-water. The temperature of the river-water during the freshet months varies from 12 degrees C. in May to 18 degrees C. in July or August. The temperature of the surface sea-water in the Strait of Georgia, near the mouth of the river, varies from 12 to 14 degrees C.; at a depth of 25 feet it is 10 to 11 degrees C. and at depths of 50 to 100 feet, 9 to 10 degrees C.

The mode of formation of the calcareous material as suggested by the mode of occurrence and the conditions under which it occurs is as follows: The lime which forms a considerable part of the material is probably derived from the shells, for the shells are partly dissolved, they usually form part of the material, and the river-water does not contain an excess of lime, the average of 22 analyses made by the Department of Mines showing only 11.85 parts per million of calcium. The analyses were made from composite samples of the river-water taken tri-weekly at New Westminster for the period of one year from May 5, 1919, to May 5, 1920. The sea-water, which contains much less lime than the river-water and is probably rendered acid by the gas formed from the decay of the wood, tends to dissolve the shells. The river-water, which displaces or mixes with the sea-water in the sand banks, tends to cause deposition of the bicarbonate of lime in solution because of the higher temperature and higher lime content of the river-water. The shells are partly aragonitic in character and hence are readily dissolved. The lime is deposited as calcium carbonate and is not readily redissolved. There is thus a mass action in the direction of deposition of the lime.

The occurrence is an unusual one and differs from the well-known "stone or rock reefs" in that the material is formed below the permanent water level. It shows that, in exceptional circumstances such as obtain in the seaward part of the Fraser delta, lithification, to some extent, of the sediments and the formation of sandy and shelly limestone and concretionary limestone may take place below the permanent water level.

ART. XXXIV.—*The Age of the Recent Delta of Fraser River, British Columbia, Canada;*[1] by W. A. JOHNSTON.

One of the problems studied in connection with an investigation of the characteristics of Fraser river, British Columbia, by the Geological Survey, Canada, in cooperation with the Department of Public Works, in 1919 and 1920, was the question of the age or time which has elapsed during the period of formation of the Recent or modern delta of the Fraser. This is of interest not only in itself, but because there has been much dispute in recent years as to whether uplift has continued into Recent time; in regions such as the Fraser Delta region where post-glacial uplift is known to have taken place.

The Recent, or modern, delta of Fraser river, British Columbia, is for the most part sharply delimited from the raised delta and marine deposits formed during the period of uplift of the land at the close of the Pleistocene. The surface of the Recent delta is all, except in a few places where the surface of peat bogs is a few feet above the general level, below the level of high tide; and the delta land high enough to be reclaimed is diked to exclude the flood-tidal and freshet waters. The head of the Recent delta, as defined by the point where the first distributary is given off, is at the city of New Westminster, 19 miles upstream or east from the seaward front of the delta in the Strait of Georgia. At New Westminster the river is confined between drift ridges or upland areas, which rise 200 to 300 feet above the river; and the river has occupied the valley between these ridges throughout the time of formation of the Recent delta. The upland area south of the river marks the inner edge of the delta, and extends from a point on the river 3½ miles below New Westminster nearly straight south to Boundary Bay. The delta is bounded on the north by the highland area extending from New Westminster nearly west to Point Grey. In its seaward part on the south side it is interrupted by the highland area of Point Roberts, an island-like drift hill which has been joined to the mainland by the construction of the delta. Above New Westminster there is a large area extending from the south side

[1] Published by permission of the Director of the Geological Survey, Canada.

of Fraser river north to Pitt lake, the surface of which is largely below the level of high tide and, therefore, may be in part considered as belonging to the Recent delta of the Fraser. A considerable part of the filling of this area, however, is stratified clay deposited during the period of uplift of the land, and parts of the delta area above New Westminster are a few feet above sea-level. It is probable, therefore, that the great part of the delta deposits of the Fraser, above New Westminster, were formed during the period of uplift following the final retreat of the Pleistocene glaciers from this region, and that the great part of the delta deposits below New Westminster have been formed during Recent time when the sea and land had their present relationship or very nearly so.

The delta is building out into fairly deep water in the strait of Georgia, and in structure presents the forms characteristic of a high-grade delta. The fore-set beds are well developed and extend from the 3-fathom line to about the 30-fathom line, and have an average dip of about 10 degrees. Below the 30-fathom line the beds slope more gradually seaward, the 100-fathom line being reached at from 1 to 2 miles from the outer edge of the sand banks, which form the seaward part of the delta. The sand banks are in large part exposed at low tide and extend seaward on an average of 4 to 5 miles from the higher delta land which is diked. The delta is building out into fairly deep water in spite of the facts that the river is tidal for a considerable distance above its mouth, with a mean tidal range of 6.4 feet and a maximum range of 15 feet at its mouth, and that the seaward front of the delta is swept by fairly strong tidal currents. The out-building occurs because of the dominance of the river currents over the tidal currents. The flood-tidal currents in the strait of Georgia run north and are the dominant tidal currents. They have the effect of giving the larger part of the subaqueous front of the delta a smooth, curved outline lacking the finger-like projections characteristic of many deltas. The steep under-water face of the delta is a characteristic feature and extends along the whole of the seaward front of the delta from the highland area of Point Grey on the north to the highland area of Point Roberts on the south, a distance of 14 miles.

The thickness of the Recent delta is known approxi-

mately at one point by a well boring at Steveston on Fraser river, 5½ miles upstream from the seaward front of the delta. The man who drilled the well stated that sand was passed through for a depth of 700 feet from the surface, a bowlder 10 feet in diameter was penetrated at 710 feet, and the first stratum of hard shale was encountered at 860 feet. The Recent delta is probably, therefore at least 700 feet thick at this point.

An estimate of the yearly rate of seaward advance of the delta for the past 60 years has been made by Mr. W. H. Boyd, Chief Topographer of the Geological Survey Branch, Department of Mines, Canada, by a comparison of the soundings made in 1859 and shown on the 1860 chart with those made in 1919 by the Hydrographic Survey of Canada. The advance seaward of the bottom of the steep under-water face of the delta, which is marked approximately by the 30-fathom line, was determined by a comparison of soundings made in 1859 with those made in 1919. The rate of advance thus determined was taken as the rate of advance of the delta. The results showed that there has been no advance in the southern (one-third) part of the delta front, the reason for this being that the flood-tidal current sweeps this part of the delta and comparatively little sediment has been delivered by the river to this part. In the central part, for a distance of 4½ miles, the rate of advance is considerable, the average of all the rates of advance, as determined at different points, being 26 feet a year. At one point the rate of advance was found to be 50.6 feet a year. The rate of advance at this point, however, is probably representative of only a very small part of the delta front. Discarding it, the average rate of advance a year of the central part of the delta is 20 feet per year. The northern (one-third) part of the delta front has also advanced because the entrance of the North Arm of the Fraser is in this part of the delta and the flood-tidal currents tend to carry northward part of the sediment brought down by the main Fraser. The average rate of advance of the northern part of the delta is probably about half that of the central part but is not definitely known because of the lack of sufficient soundings for purposes of comparison. The average rate of advance of the delta as a whole is probably, therefore, about 10 feet a year.

The age of the Recent delta may be approximately

determined by assuming that the rate of seaward advance of the delta as determined for the past 60 years has been uniform during the time of formation of the delta, and dividing the rate into the distance of advance of the delta. The average distance from the inner edge of the delta along the highland below New Westminster to the seaward front of the delta is about 80,000 feet. Dividing this by 10 feet gives 8,000 years as the age of the Recent delta. It is possible, however, that the rate of advance has varied in the past and that part of the delta above New Westminster was formed in Recent time. Hence these figures have little absolute value, but they seem to show, nevertheless, that the relationship of sea and land in the Fraser delta region has been nearly if not quite stable for several thousand years and that the last uplift of the land or lowering of sea-level took place probably not more than 10,000 to 12,000 years ago.

The writer is indebted to the late Commander Musgrove of the Department of the Naval Service of Canada, under whose direction the soundings in the strait of Georgia were made in 1919, for records of the soundings; and to Mr. W. H. Boyd, Chief Topographer of the Geological Survey, Canada, who correlated the soundings in 1859 and in 1919 and determined the rate of advance of the delta.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Separation of Gallium from Indium and Zinc by Fractional Crystallization of the Cæsium-Gallium Alum.*—The separation of gallium and indium by this method was briefly described by Uhler and Browning in this Journal in 1916 (**42**, 389). This method has now been studied quantitatively by Philip E. Browning and Lyman E. Porter. Starting with 7.5 g. of mixed hydroxides containing 26.5 parts of gallium oxide to 73.5 parts of indium oxide, they dissolved this in sulphuric acid, added a little more than the theoretical amount of cæsium sulphate, neutralized most of the free acid with sodium hydroxide, ad then crystallized from a volume of 250 cc. The first crop gave a product with 85.1 parts of gallium oxide to 14.9 parts of

indium oxide. After five recrystallizations, the crystals at the least soluble end consisted of pure cæsium-gallium sulphate, while the fifth mother-liquor contained gallium and indium oxides in the ratio of 0.6 to 99.4.

It was found that when 1 g. of pure cæsium-gallium alum was mixed with 0.2 g. of zinc oxide dissolved in sulphuric acid and with 0.1 of cæsium sulphate a single crystallization gave a product with 98 parts of gallium oxide to 2 of zinc oxide, while a recrystallization of this gave a crop in which zinc could not be detected. The results show that the method is an excellent one for the purpose.—*Jour. Amer. Chem. Soc.*, **43**, 126. H. L. W.

2. *A Text-Book of Practical Chemistry;* by G. F. Hood and J. A. Carpenter. Large 8vo, pp. 527. Philadelphia, 1921 (P. Blakiston's Son & Co. Price, $5.00 net).—This is intended to be a reference book for students in connection with experimental laboratory courses. It embraces inorganic preparations, qualitative analysis, quantitative analysis, organic preparations, organic analysis, and physical chemistry, and in each of these main sections there is a careful classification of the matter presented, so that by means of suitable chapter-headings easy reference is assured.

The book gives a favorable impression as a very useful one for students and teachers in laboratory courses, for it gives a vast amount of accurate information in regard to laboratory experiments in various courses of study. Naturally there are differences of opinion in regard to the best methods of procedure in certain operations. For instance, this book states that it is undesirable to use the Gooch crucibles for precipitates that have to be ignited, it recommends the use of gentle suction only in employing it, and it advises the introduction of a perforated porcelain filter plate between two layers of asbestos when preparing it for filtration; whereas, there is no doubt that precipitates may be ignited to redness in the Gooch crucible with the most satisfactory results, that strong suction is desirable to prevent the displacement and running through of the asbestos, and that the filter plate is superfluous when strong suction is used. In view of these facts it appears that some, at least, of the British chemists are not taking full advantage of the important American device, the Gooch crucible.

A good feature of the book is the introduction at the end of each main section of references to the literature of the subject, such as monographs and text-books. H. L. W.

3. *A Dictionary of Chemical Solubilities, Inorganic;* by Arthur Messinger Comey and Dorothy A. Hahn. 8vo, pp. 1141. New York, 1921 (The Macmillan Company).—This work is to be welcomed as an exceedingly important addition to chemical books of reference. The first edition, by Dr. Comey alone, appeared 23 years ago, and much material has accumulated since that time, as is shown by the fact that this second edition has mo[illegible]e as many pages as the earlier one.

Comey's dictionary gives full quantitative data regarding the solubility of inorganic substances, as well as the specific gravities of solutions in many cases, but the unique feature of the work is the fact that it attempts to mention and give the formula of every inorganic compound that has been analyzed. This last feature gives the book a particular importance and usefulness as a book of reference, for it affords an alphabetically arranged list of all the inorganic compounds with references to the original literature. In many cases little is known about the solubility of the compounds, but even the statements given in such cases, showing that they are soluble or insoluble in water, soluble or insoluble in certain acids, decomposed by water, etc., are frequently very useful items of information to chemists.

Comey's dictionary is based in plan upon that of Professor Storer, published in 1864, which some of our older chemists remember as an interesting and important source of reference before the time of the appearance of the more modern work under consideration.

The great amount of labor involved in the preparation of this dictionary deserves much praise, and it appears that the effort was well worth while in producing a book of such usefulness.

H. L. W.

4. *Inorganic Chemistry for Schools and Colleges;* by JAMES LEWIS HOWE. 8vo, pp. 443. Easton, Pa., 1920 (The Chemical Publishing Co.).—This text-book now appears in its revised second edition, thirteen years after its first publication. In the presentation of the subject much attention is paid to the Periodic Law. For instance, separate chapters are devoted to the elements, the hydrides, the halides, etc., in each case with arrangements according to the periodic groups. There are undoubtedly some advantages in this plan, but it brings the descriptions of the metals and their various compounds into several different parts of the book.

The book presents the fundamental principles and facts of chemistry very clearly, and it is admitted that there is much intentional repetition in order to facilitate thorough teaching. The practical applications of chemistry are rather fully treated and at the end of the book three is an excellent chapter on metallurgy.

A course of simple but instructive laboratory experiments is given by means of concise directions in small print at the bottoms of the appropriate pages.

The author states that he has made no attempt to incorporate many of the recent advances in chemistry into his elementary book, but, nevertheless, in view of its importance in connection with the atomic theory, it is somewhat unexpected to find no reference to radioactivity when radium is mentioned and to find niton omitted from the periodic table. H. L. W.

5. *Luminous phenomena in the Lilienfeld tube.*—The peculiarity of the Lilienfeld X-ray tube is that the electrons emitted

from the hot filament after passing through a small hole in the main cathode are accelerated in a strong field and may be brought to a very sharp focus on the target which is inclined at an angle of 45° to the path of the beam.

The authors of this paper, J. E. LILIENFELD and F. ROTHER, report the formation of a luminous ring of light, blue-gray in color, and of elliptical form, just at or above the surface of the anticathode. The size of the ellipse increases with higher potential discharges but remains similar in form. Examined with a polariscope the light is almost completely plane-polarized with the electric vector parallel to the line of intersection of the plane of symmetry of the tube with the surface of the target.

The spectrum was similar to that which would have resulted from a high temperature but with limits dependent somewhat upon the conditions of excitation of the tube. The intensity of the short wave end compared to the long wave end was so very much greater than with ordinary light sources as to imply an exceedingly high temperature. It is their idea that the radiation arises in an electron layer just at the front of the anticathode, which is excited by the cathode rays and that the connection between this layer and the electrons lying a little deeper in the plate is so close that the visible spectrum probably passes over uninterruptedly into the continuous Roentgen spectrum. The paper is illustrated with photographs of the spot and its spectrum together with comparison spectra from helium and a metal filament.—*Phys. Ztschr.* **21**, 249, 1920. F. E. B.

6. *Observations on Soaring Flight.*—Although the exact nature of soaring flight still remains an unexplained problem of physics a summary of observations by DR. E. H. HANKIN extending over a period of ten years and recently communicated to the Cambridge Philosophical Society is deserving of attention. The observations were carried on in a tropical country where the meteorological conditions are more stable than in temperate latitudes, and were made not only upon birds, but also upon dragon flies and flying fishes.

The two points of novelty in the author's view are, (1), that the wing sections of the best soaring birds and in the soaring dragon flies are characterized by transverse ridges projecting on the under side of the wing. A similar feature is significantly present in the *puttung*, a form of Indian kite which flies vertically over its string; (2), that the slow soaring flight in all three classes of animals is seemingly dependent upon the presence of sunshine, while fast soaring flight is always dependent upon the presence of wind.

That soaring flight is not due to undiscovered wing movements is a conclusion drawn from the means used to brake the flight in the case of dragon flies and of flying fishes. Arguments are presented that soaring flight is neither due to lateral gusts of wind, to ascending currents nor to turbulencies whose presence could

be detected by the motion of small masses of discrete cloud material, the behavior of numerous floating seeds, or small floating feathers.

It is the author's conclusion that since the most attentive observation has failed to suggest a solution of the problem, the only hopeful method of attack is by way of direct experimental investigation. A list of twelve articles detailing the author's observations is appended to the communication.—*Proc. Camb. Phil. Soc.* **20**, 227, 1920. F. E. B.

7. *Elementary Calculus;* by WILLIAM F. OSGOOD. Pp. ix, 224. New York, 1921 (The Macmillan Co.).—A new text on Elementary Differential Calculus which aspires to attention in this well-occupied field should present some special claim to recognition. The author's aim to present the subject with emphasis on the ideas and methods of the calculus and their use in solving problems in physics and geometry, is well maintained. The tendency of the student to regard differentiation as a mechanical process whereby an answer is to be obtained is strongly deprecated and the illustrative examples are so selected that they should seem to him as of interest and value.

More than usual pains has been taken to make the logic rigorous, which will doubtless appeal to the mathematicians. On the other hand the illustrations used are so concrete and physical that they afford the very kind of mathematical training which the physics teacher desires his students to have had.

Of the eight chapters, one describes the character of the simple functions, and five are devoted to the manner and result of their differentiation. Chapter II discusses the application of derivations to curves, to maxima and minima, to velocity and to rates. Chapter VII is the most unusual in a book of this scope. In it is presented a valuable discussion of the methods of graphical solution and approximation for numerical equations which do not come under the standard rules of algebra and trigonometry.

It is a book which merits the attention of teachers of Freshman courses in colleges and technical schools. F. E. B.

8. *Space, Time and Gravitation;* by A. S. EDDINGTON. Pp. vii, 218. Cambridge, 1920 (Cambridge University Press).—The author is one of the most prominent of the English protagonists of the relativity theory. The purpose of the book is to expound the theory and its implications without the use of much technical mathematics, but with strong emphasis upon the rightness of the author's view. The polemical character of the book is evident in the introductory chapter which is cast into the form of a dialogue between a physicist, a mathematician, and a relativist, in which the physicist becomes somewhat involved in a metaphysical fog.

The first three chapters are devoted to the Fitz-Gerald contraction and the geometry of the space-time manifold. The next three chapters show how on the equivalence theory all the forces

of nature might be merged into the spacial relations. The five succeeding chapters discuss some of the consequences of the theory and their experimental investigation. The twelfth and final chapter gives some of the author's speculations upon the nature of things which seem to be summed up in the concluding paragraph which reads: "We have found a strange foot-print on the shores of the unknown. We have devised profound theories one after the other to account for its origin. At last we have succeeded in reconstructing the creature that made the foot-print. And Lo! it is our own."

The book will give the reader a good idea of the Einstein theory and how it has led to the prediction of three exceedingly minute quantities, namely, the secular motion of the perihelion of Mercury, the deviation of ray of light passing close to the sun, and the change in frequency of radiation in an intense gravitational field, for all of which evidence is now supposed to have been found. On the other hand the book seems, at least to one reader, too dogmatic in its presumption that the physical world is but the stuff of our consciousness and that physical phenomena are due to the oddities of space. The attitude of the physicist in general is a little more tolerant. He is content to specify such postulates or abstractions from the complex world of reality as are sufficient for the set of problems in hand and later if experiment shows that these are too limited he is frankly willing to extend them. For example, the ordinary problems of hydrodynamics are well enough discussed on the assumption of a continuum, but he does not feel that he must be held to this assumption when treating of the chemical properties of water or of the radiations from the hydrogen atom. Similarly if it should appear that time does not run on at a uniform rate, or that it is desirable to assume that it is discrete in structure, possessing something like the quantum in energy, doubtless the physicist will be ready to adopt the new hypothesis, only he will insist that it corresponds to something real in nature.

While there is no doubt that the interlacing of space and time into a differential quadratic affords a valuable technique for the solution of problems in electrodynamics, the question whether a whole philosophy of nature based on an absolute velocity, as of light, will win universal acceptance, must still be considered an open one.

The reader who may care for a more open-minded discussion of the subject will be interested to read the article on *Gravitation and Light* by Sir Joseph Larmor in the Proceedings of the Cambridge Philosophical Society, **19**, 324, 1920. F. E. B.

9. *The Principle of Relativity;* by H. WILDON CARR. Pp. vii, 163. London, 1920 (Macmillan and Co.).—This little book on the philosophical aspects of relativity is the outcome of a course of lectures on "Historical Theories of Space, Time and Movement" delivered by the author at Kings College last year.

The major portion of the book is taken up with a discussion of the speculations of the metaphysicians on the meaning of movement from the days of Zeno and Aristotle down to recent times. Although the author's treatment is historical in the main, he fails to give Lorentz and Larmor the great credit which they deserve for the theoretical development whose only logical outcome was Einstein's principle of relativity. The author has a chapter entitled "In what Sense is the Universe Infinite," but he does not mention Einstein's and De Sitter's interesting speculations on a re-entrant universe. The book is of more interest to professional philosophers than to physicists or mathematicians.

L. P.

II. Geology.

1. *Zur Älteren Geschichte des Diskontinuitätsproblems in der Biogeographie;* by Nils von Hofsten. Zoolog. Annalen, **7**, 197-353, 1916.—This essay on the theories of the variable distribution of plants and animals is limited to the living world, and does not consider the life of the past ages. The presentation is clearly and interestingly written by a biologist along historical lines. It begins with the theories of the Greeks as set forth by Hippocrates and Aristotle, who thought the distribution to be due to differences in the local climates, and follows the more essential ideas down to the present time. For a while the church stimulated this research because of the riddle of the wide distribution and variability of man, but in the end it fought the conclusions of the naturalists.

Modern views began with the discovery of America, with its plants and animals which are different from those of Europe. Some continued to explain this difference by special local creations, and in fact Louis Agassiz (1850-1859) held to the creation theory to the end of his life. Buffon (1749-1756) is sometimes regarded as the originator of modern views in regard to biogeography. The way was further indicated by Cuvier (1815), Lyell (1830-1833), Heer (1845), and Forbes (1846), and modernized by Hooker, De Candolle, Darwin, and Wallace. Now we know that the organisms are where they are because of local genetic developments out of antecedent stocks, conditioned by their variable dispersion and evolution along varying routes of travel and climate, and that this variation was brought about in the main by the geologic changes in the configuration of the land surfaces and their oceanic boundaries. C. S.

2. *Recent Molluscs of the Gulf of Mexico and Pleistocene and Pliocene Species from the Gulf States. Part I: Pelecypoda;* by Carlotta J. Maury. Bull. Amer. Paleontology, vol. **8**, No. 34, 113 pp., 1 pl., 1920.—This is an annotated bibliography, with synonyms, of 345 forms of pelecypods, as limited by the title, along with their distribution and occurrence in the Gulf coast area. Only one new species is described. C. S.

3. *Brachiopoda Triadica;* by C. Diener. Fossilium Catalogus, 1: Animalia, Pars 10, pp. 109, Berlin (W. Junk), 1920.—This catalogue cites the bibliography of all the known Triassic brachiopods, which are divided as follows: Inarticulata, 3 genera, 26 species; Strophomenacea, 2 genera, 10 species; Spiriferacea, 12 genera, 260 species; Rhynchonellacea, 5 genera, 184 species; Terebratulacea, 8 genera, 146 species; total, 30 genera, 626 species. Five-sixths of the forms are restricted to the alpine-mediterranean province; 19 occur in Germany, 77 in the Himalayan area, 14 are boreal, and only 4 andine. C. S.

4. *Cephalopoda Dibranchiata;* by E. v. Bülow-Trummer. Fossilium Catalogus, 1: Animalia, Pars 11, pp. 313, Berlin (W. Junk), 1920.—In this work is brought together all the literature treating of the fossil dibranchiate cephalopods. It has taken the author more than two years to prepare the manuscript, and all paleontologists should be thankful that the work has been done once for always. Thirteen genera are restricted to the Cenozoic, and fifty-eight to the Mesozoic. C. S.

5. *Coal in Great Britain;* by Walcott Gibson. Pp. viii, 311, 8 pls., 50 text figs. London (Edward Arnold), 1920.—The author, after thirty years' experience in the coal fields, presents here a condensed but readable account of the geology of the coal of the late Paleozoic formations, mainly for mining engineers, mine owners, and mining students of Great Britain. The book should be interesting, however, to mining geologists in other countries. The first eight chapters are introductory to the geology of coal, and describe the nature, formation, origin, distribution, and something of the included fossils as zonal indices, together with chapters on prospecting and boring and on the stratigraphy of the exposed and concealed coal fields. The remaining fifteen chapters treat of the widely distributed coal fields of England, Wales, Scotland, and Ireland.

"The distribution of coal according to quantity has been estimated for each continent, and is as follows in millions of tons: Europe, 789,090; Asia, 1,279,586; Oceania, 170,408; Africa, 57,839; America, 5,111,528. According to the class of coal, the world's estimated supply of anthracite coal is 496,846; of bituminous coal, 3,902,944; of sub-bituminous and brown coal, 7,397,553 millions of tons. In these estimates no allowance has been made for coal not mineable or for loss in mining" (p. 32). C. S.

6. *A Monograph of the British Ordovician and Silurian Bellerophontacea,* Part I; by F. R. Cowper Reed. Palæontographical Soc., pp. 1-48, pls. 1-8, 1920.—In this interesting but uncompleted study of British *Bellerophon*-like gastropods are described and illustrated the species of the following genera: *Sinuites* (syn. *Protowarthia*), 15 forms (9 new); *Sinuitopsis,* 1 n. sp.; *Oxydiscus,* 5(2); *Cyrtolites,* 5(4); *Isospira,* 1 n. sp.; *Bucaniella,* 2(1); *Bucania,* 4(3); *Kokenospira,* 10(7); *Tetranota,* 4(3); *Conradella,* 4(3); *Temnodiscus,* 2 n. spp.

The author arranges the genera in three groups: (1) *Integridorsata* (without median slit, band, or row of perforations; (2) *Fissidorsata* (with fissure); and (3) *Terebridorsata* (with median perforations). C. S.

7. *West Virginia Geological Survey;* I. C. WHITE, State Geologist.—Another of the valuable detailed County reports of the West Virginia Geological Survey has appeared. This is devoted to Webster County and the author is DAVID B. REGER. It embraces xiv, 671 pages with 35 plates and 24 text figures. There is also a series of topographic and geologic maps in a separate case. Webster County contains the northwest extension of the famous New River Coal Group, as also the Kanawha Group and the lower members of the Allegheny Series in its northern portion. The price, including case of maps, delivery charges paid by the Survey, is $3.00; in combination with other volumes of the Survey, a special rate is made. Extra copies of topographic map cost 75 cents; of the geologic map, $1.00. The Survey may be addressed at Morgantown, W. Va. (P. O. Box 848.)

III. ZOOLOGY AND BOTANY.

1. *Sanitary Entomology: The Entomology of Disease, Hygiene, and Sanitation;* edited by WILLIAM DWIGHT PIERCE. Pp. xxvi, 518, with 28 plates and 88 text-figures. Boston, 1921 (Richard G. Badger; price $10).—Just at this time, when there is such fear that the insect-borne diseases now raging in central and eastern Europe may become established in America, this untechnical treatise on the relations of insects and disease in all parts of the world is most opportune. The book is the outcome of a series of studies prepared by ten specialists for the training of a large number of people for any service which might be required in combating disease-carrying insects during the war. This information is of no less importance, however, in the prevention of disease now that peace between so many of the nations has been officially declared, for the louse and other insects continue their daily additions to the millions of deaths for which they have been responsible during the past few years.

The treatment of the subject is entirely untechnical, so that any intelligent person, without previous knowledge of biology, can learn the essential facts about the various ways in which insects transmit the germs of diseases both to man and domesticated animals and the practical methods by which these diseases can be prevented or eradicated. The control of all kinds of insect pests in dwellings, farm-yards, packing houses and communities is also given in detail, with recipes for remedial treatment.

The book includes not only the insects but also the mites and ticks, for the latter rival the insects in the transmission of diseases of domesticated animals, as well as by causing injuries by

their parasitic habits. Simple directions are given for distinguishing the injurious from the harmless species of the various groups, for the protection of man and each of his domesticated animals from the former, and for the treatment of persons or animals suffering from these parasites.

The book will not only serve as a guide to the study of insects in relation to disease, but it is the most useful handbook available for the sanitary officer, health inspector, nurse, and physician in their professional duties. W. R. C.

2. *Embryology of the Chick;* by BRADLEY M. PATTEN. Pp. ix, 167, with 182 figures.—Philadelphia, 1920 (P. Blakiston's Son and Co.).—This little book consists of an untechnical description of the development of the chick during the first four days of incubation, during which period the principal organ-systems of the body are established. As it is designed particularly for the beginner in the study of embryology, all unessential details have been omitted and the discussion limited to the fundamental processes involved. The well-executed and fully labelled diagrams make as easy as possible the student's path through one of the most difficult, although one of the most fascinating, fields of biology. W. R. C.

3. *University of Iowa Studies in Natural History: The Barbados-Antigua Expedition;* by C. C. NUTTING. Pp. 274, with 50 plates. Iowa City, 1919 (published by the University).—This is a delightful narrative of a collecting trip to the West Indies by a party of teachers and advanced students from the zoological department of the University of Iowa. The work of the party from day to day and the discoveries of strange forms of marine life which were made, as well as descriptions of the islands themselves, their natural resources, and the life of their human inhabitants, are recorded in a vivid style which bears witness not only to the enthusiasm and skill of the author but also to the charms of these wonderful tropical islands. In addition to the delightful story of the expedition, the book is a real contribution to science, for there are several chapters of zoological notes, recording observations on the habits of the terrestrial and marine animals of the region. W. R. C.

4. *The Origin and Development of the Nervous System from a Physiological Viewpoint;* by CHARLES MANNING CHILD. Pp. xvii, 296, with 70 text-figures. Chicago, 1921 (The University of Chicago Press).—The author here applies to the development of the nervous system his theory of axial gradients of susceptibility. He shows that both the protoplasm and the organism exhibit an "organismic pattern" of physiological gradients, the evolutionary development of which leads in the higher animals to the complex excitation-transmission relations of the nervous system; that is, "from the simple physiological gradient to the ego." With the support of extensive experimental evidence and a consideration of all groups of organisms

the author concludes "that in the excitatory relation between protoplasm and the external world and the effects of such excitation on protoplasm we have an adequate physiological basis for organismic pattern and for the physiological continuity of development." W. R. C.

5. *The Cactaceæ: Descriptions and Illustrations of Plants of the Cactus Family;* by N. L. BRITTON and J. N. ROSE. Volume II, pp. vii, 239, with 40 plates (32 colored) and 304 text-figures. Washington, 1920 (Carnegie Institution, Publication 248, Volume II).—The second volume of this important work fully maintains the high standard set for it by the first (see this Journal, **49**, 222). Of the eight subtribes into which the authors divide the very large tribe Cereæ, only the first two, the Cereanæ and the Hylocereanæ, are here discussed. The Cereanæ are erect or bushy cacti and include 138 species divided into 38 genera; the Hylocereanæ are vine-like cacti and include 49 species divided into 9 genera. Of the genera recognized 18 are monotypic, 22 of the others have 10 species or less, while the following genera are represented by more than 15 species apiece: *Cereus, Cephalocereus, Lemaireocereus, Trichocereus, Harrisia, Hylocereus* and *Selenicereus.* The new genera proposed number 19, of which eleven are monotypic; the new species proposed number 48. Perhaps the most striking of all the species described is the giant cactus, *Carnegiea gigantea,* of Arizona and the adjacent parts of California and Mexico. This remarkable plant with its erect columnar trunk sometimes attains a height of 12 meters and a diameter of over half a meter. Other interesting and attractive cacti are the night-blooming cereuses, of which *Hylocereus undatus* is the best known. Some of the most beautiful of the colored plates, all of which were executed by Miss M. E. Eaton, represent the large and showy flowers of this and similar species. A. W. E.

6. *Phytoplankton of the inland lakes of Wisconsin.* Part I. *Myxophyceæ, Phaeophyceæ, Heterokonteæ, and Chlorophyceæ exclusive of the Desmidiaceæ;* by GILBERT MORGAN SMITH. Pp. 243, 51 plates. Madison, Wisconsin, 1920 (Wisconsin Geological and Natural History Survey, Bulletin No. 57).—The numerous lakes of Wisconsin have afforded an exceedingly favorable field for the study of our fresh water plankton, and Professor Smith's volume is an important addition to our scanty knowledge of the subject. Over two hundred lakes were investigated, the plankton being collected by means of nets with very fine meshes. After a very useful key to the genera, based on vegetative characters, the species observed are fully described, together with the genera and higher groups under which they are distributed. Wherever necessary, specified keys to species, genera or other groups are included. In all 227 species are recognized, 54 belonging to the Myxophyceæ (or blue green algæ), 18 to the Phaeophyceæ (or brown algæ), 10 to the Heterokonteæ, and the remainder

to the Chlorophyceæ (or green algæ). The 51 plates illustrate every species and variety observed and are to be commended for their accuracy and beauty. Several of the forms are here figured for the first time, but even where earlier figures have been published these have often appeared in scattered papers difficult of access. It is therefore a great satisfaction to have these new figures gathered together in a single work. A. W. E.

7. *An Introduction to Bacterial Diseases in Plants;* by ERWIN F. SMITH. Pp. xxx, 688, with frontispiece and 453 illustrations. Philadelphia and Iondon, 1920 (W. B. Saunders Company).—The rapid advances made in the important field of bacterial plant diseases are intimately associated with the investigations of Dr. Smith. The present volume will therefore be most welcome, not only to plant pathologists but to botanists in general. The material presented is divided into five parts. The first deals with the more general features of bacterial diseases, the following subjects being among those discussed: distribution among the families of flowering plants, period of greatest susceptibility, method of infection, morphological and cultural features of the bacteria, reactions of the host plant. The second part takes up in detail the methods of research. The third, which occupies 340 pages, gives full descriptions of fourteen important bacterial diseases of economic plants, each being accompanied by references to the literature. The fourth part suggests subjects for special study, discusses the formation of tumors in plants, and gives an account of teratosis in the absence of both tumors and parasites, using for illustration the remarkable *Begonia phyllomaniaca.* The concluding part contains excellent advice to the botanist and especially to the plant pathologist regarding research work and matters pertaining to it either directly or indirectly. The book is profusely illustrated, many of the figures being photomicrographs of diseased plant tissues, reproduced by fine half tones. A. W. E.

8. *Text-book of Pastoral and Agricultural Botany, for the Study of the Injurious and Useful Plants of Country and Farm;* by JOHN W. HARSHBERGER Pp. xiii, 294, with 121 text-figures. Philadelphia, 1920 (P. Blakiston's Son & Co.).—For the past twenty-five years the author has given a course in botany to a class of veterinary students, and the present volume is based upon this course. As might be expected some of the topics treated do not find a place in the usual text-books of botany. This is particularly true of the first nine chapters, in which poisonous plants are discussed, not only from the standpoint of their botanical features but also from the standpoint of the various symptoms which they produce in poisoned animals. The remaining chapters deal with important food plants, with soil-nitrogen, with weeds, and with agricultural seeds. A full bibliography is given at the close of each chapter, and directions for laboratory work are interspersed throughout. A. W. E.

9. *Heredity and Evolution in Plants;* by C. STUART GAGER, Director of the Brooklyn Botanic Garden. Pp. v, 265, with 112 text-figures. Philadelphia, 1920 (P. Blakiston's Son & Co.). —The author here gives us a revision of certain chapters in his Fundamentals of Botany, published in 1916. These chapters furnished a concise but very clear treatment of the various theories connected with the heredity and evolution of plants, strong emphasis being laid upon recent experimental methods of investigation. Two chapters, not in the earlier work, deal with geographical distribution of plants and with the great taxonomic groups into which plants have been divided. A valuable bibliography concludes the volume. A. W. E.

10. *Diseases of Economic Plants;* by F. L. STEVENS and J. G. HALL; revised edition by F. L. STEVENS. Pp. vii, 507, with 237 text-figures. New York, 1921 (The Macmillan Company).—The first edition of the present work was published in 1910. The revised edition is designed to meet the special needs of college students, and a part of the revision consists in the rearrangement of the subject matter. Many diseases of major importance, however, have come into prominence during the past ten years and descriptions of these naturally find a place in the new volume. There are likewise a number of new illustrations, and certain modifications of treatment are recommended. With but few exceptions the diseases discussed are these caused by fungous parasites. A. W. E.

11. *The Nature-Study of Plants in Theory and Practice for the Hobby-Botanist;* by THOMAS ALFRED DYMES. Pp. xviii, 173, with frontispiece, 5 plates and 51 text-figures. London, 1920 (Society for Promoting Christian Knowledge).—The subject-matter of this attractive little book is divided into two parts, the first entitled "Theory" and the second "Practice." In the first part the scope of nature-study is defined, and the various "factors of life" are discussed with reference to the "life and preservation of the individual" and also with reference to the "preservation of the race." In the second part a common British plant, the Herb Robert (which is likewise common in North America), is thoroughly considered in its numerous aspects, the life-history being followed step by step from the germination of seed to the dispersal of the ripened fruitlets. The intensive study of a single species, which is here recommended, meets the approval of Professor F. E. Weiss, of Manchester, who has supplied an introductory note to the volume. A. W. E.

12. *The Chemistry of Plant Life;* by ROSCOE W. THATCHER. (McGraw-Hill Book Co.), New York. Pp. xi, 268.—This is a text-book of biochemistry written for the use of students of botany and drawing its illustrations from the facts and problems of the plant kingdom. The volume presupposes training in inorganic and organic chemistry on the part of the reader. It deals with composition rather than the dynamics of living matter, but

its chemistry is of the up-to-date variety. Something of this sort—a diminutive Czapek—has long been needed for the use of those workers in biochemistry who are interested primarily in plant rather than animal tissues. L. B. M.

IV. Miscellaneous Scientific Intelligence.

1. *The Carnegie Foundation for the Advancement of Teaching. Summary of Fifteenth Annual Report of the President,* Henry S. Pritchett, and *Treasurer,* Robert A. Franks. Pp. vi, 171. New York, 1920 (522 Fifth Avenue).—The total resources of the Carnegie Foundation now amount to $24,628,000, of which $15,192,000 belong to the permanent general endowment, $7,571,000 to a reserve fund to be spent in the retirement (during the next sixty years) of teachers now in associated institutions, $1,250,000 to the endowment of the Division of Educational Enquiry, and $390,000 to a reserve fund to be expended in aiding universities and colleges to adopt the new plan of contractual annuities.

During the fifteen years of its existence the Foundation has distributed nearly $8,000,000 in retiring allowances and pensions to 909 persons. Of this Harvard has received $625,000, Yale, $548,000, and Columbia, $464,000. Sixteen other universities have each received between one and two hundred thousand dollars each. The remainder has gone to eighty different institutions. There are now operative 356 retiring allowances and 199 widows' pensions, entailing an annual expenditure of $870,-670. The average retiring allowance paid is $1,568.

During the past year three institutions, Bryn Mawr College, Queen's University, and Whitman College, were added to the list of associated institutions, and twelve institutions, in addition to the twenty-nine that had already done so, formally adopted the new plan of contractual annuities—The Teachers Insurance and Annuity Association of America, established by the Foundation to provide insurance and annuity protection for college teachers without overhead charges, has written 653 insurance policies covering $3,356,747 of insurance and 554 annuity contracts providing $624,398 annual income at retirement. The special features of the new retiring allowance system of Harvard University are discussed at some length. By this plan each teacher appointed for more than one year is required to contribute 10 per cent of his annual salary to a fund which is to be invested by the Corporation and to be used, together with its accumulations, to purchase at his retirement an annuity in some company approved by the Corporation. The general subject of pension legislation is also treated in detail as in earlier reports, and many points open to criticism are pointed out. Attention is called to the fourteenth bulletin on the *training of teachers for public schools* (see vol. **50**, p. 171); also to a third bulletin on *legal education* soon to appear.

2. *National Academy of Sciences.*—The annual meeting of

the National Academy of Sciences will be held at the Natural History building, U. S. National Museum, in Washington on April 25, 26, and 27. The preliminary program of scientific sessions gives a list of 33 papers to be presented. It is also announced that an address will be delivered Monday evening by Albert I, Prince of Monaco, Agassiz medalist, in the auditorium of the U. S. National Museum. A reception follows the address.

3. *Science News Bulletin.*—The establishment of an organization for the purpose of familiarizing the general reading public with the progress of scientific research has been recently established in connection with the National Research Council. The new organization, to be known as "Science Service" has been substantially endowed and is chartered as a non-profit-making corporaion. Its control is vested in a board of Trustees composed of ten scientists and five journalists. The National Academy of Sciences, the American Association for the Advancement of Science and the National Research Council each elects three trustees.

The personnel of the first board of trustees is announced as follows: A. A. Noyes, R. A. Millikan, John C. Merriam, D. T. MacDougal, George I. Moore, J. McKeen Cattell, George E. Hale, Vernon Kellogg, R. M. Yerkes, E. W. Scripps, R. P. Scripps, W. E. Ritter, William Allen White, Chester H. Rowell, Edwin F. Gay.

The charter of the new organization is a wide one, authorizing Science Service to employ newspapers, periodicals, books, lectures, conferences, motion pictures and any similar educational agencies in the distribution of scientific information. Edwin E. Slosson is to be the editor of Science Service. The policy of the Service is to be one of coöperation rather than competition with existing press associations, news agencies and syndicates. It will aim to supply accurate and interesting articles on all branches of science and technology at the lowest possible cost. Offices have been opened in the National Research Council Building, 1701 Massachusetts Avenue, Washington.

4. *French-English Medical Dictionary;* by Alfred Gordon. Pp. 161 (P. Blakiston's Son & Co.) Philadelphia.—The recrudescence of interest in French medical literature is one of the by-products of the World War. It lends timeliness to the publication of glossaries of scientific expressions, particularly in those fields, like medicine, where progress has been rapid and the technical vocabulary has been expanded by the addition of many new words. Gordon's dictionary is compact and easily used. One is surprised by an occasional omission such as that of "anaphylaxie," a preeminently French contribution to science, not to mention missing up-to-date expressions like "vitamine" and "opsonine." The book has an excellent simple scheme for aiding in the correct pronunciation of each French word. L. B. M.

5. *Laboratory Manual for the Detection of Poisons and Powerful Drugs;* fifth American edition; by Wilhelm Autenrieth

and WILLIAM H. WARREN. Pp. xv, 342. Philadelphia (P. Blakiston's Sons & Co.).—There are all too few dependable manuals of toxicology published in the English language. Among them the translated edition of Autenrieth's well known "Auffindung der Gifte" has attained a deserved popularity. The present book is essentially like the fourth American edition, the only change of importance being the introduction of tests for wood alcohol by the translator, Dr. Warren. L. B. M.

6. *An Introduction to Chemical Pharmacology;* by HUGH MCGUIGAN. Pp. xii, 418. Philadelphia (P. Blakiston's Son & Co.).—This is different from any book which we can recall, bearing the title of Pharmacology. It is essentially a very compact compendium of facts derived for the most part from organic chemistry and biochemistry and classified according to a chemist's scheme. Indeed it is almost cyclopedic in character. It is well enough to recognize the current popularity of the chemical viewpoint in the biological sciences; but chemical classification, structural formulas, and tests for the identification of drugs are only a part of the equipment needed by the student to realize the "reactions of living matter brought about by drugs." The selection of topics seems almost too comprehensive. Why, for example, should a "Method for Preparing Pectin" be incorporated in a book for students of pharmacology? Numerous topics, particularly such as deal with the metabolism of foods, also seem out of place in such a volume which can at most supplement, not replace, the conventinal textbooks on the action of drugs.

L. B. M.

7. *New York State Income Tax Procedure, 1921;* by ROBERT H. MONTGOMERY. Pp. ix, 682. New York, 1921. Montgomery's Tax Procedure, 1921, volume III (The Ronald Press Company; price $5, in cloth).—Mr. Montgomery's New York State Income Tax Procedure, 1921, is an outgrowth and amplification of that portion of his 1920 edition of Income Tax Procedure in which he discussed the differences between the New York State procedure and the Federal income tax procedure. He deals at length with the New York personal income tax and more briefly with the New York franchise tax on corporations. Several appendices are also included, and of considerable value. One of these contains a set of the various forms as at present used, filled in in some instances so as to serve as illustrations, and another contains the opinions handed down by the courts in various cases which have come before them with reference to New York income tax matters.

The book should prove of great assistance to those who have to prepare returns either for individuals or for corporations under the present New York laws. In dealing in quite limited space with any such complex subject there must of necessity be many questions left unanswered and many topics only superficially discussed, but considering the space at the author's disposal, he covers the subject quite fully. J. D. D.

HENRY ANDREWS BUMSTEAD

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

HENRY ANDREWS BUMSTEAD.

Henry Andrews Bumstead was born in Pekin, Illinois, on March 12th, 1870. His father was Samuel Josiah Bumstead, a physician of local prominence, and his mother, Sarah Ellen Seiwell. His early education was obtained at the Decatur, Illinois, High School, from which he went to Johns Hopkins in 1887, expecting to study medicine. There he came under the influence of Rowland, who stimulated the interest in physics which he had already shown. After receiving his B.A. degree in 1891, he remained in Baltimore for two years as an assistant in the physics laboratory. In 1893 he was brought to Yale as an instructor by Professor Hastings. He continued his study of physics in the Yale graduate school, and obtained his doctor's degree in 1897. In 1900 he was promoted to an assistant professorship, and six years later he became Professor of Physics in Yale College and Director of the Sloane Laboratory. The year before receiving his doctor's degree he married Luetta Ullrich, of Decatur, Illinois, who survives him.

Professor Bumstead's thesis for the doctor's degree, which does not seem to have been published, contains a critical survey of electrodynamic theories in vogue at the time at which it was written. He states in the introduction that his object is "to set forth the true position of the experiments of Hertz in the history of the development of our knowledge of electricity; and to trace, in some measure, the influence of Helmholtz in the establishment of the true theory of electrodynamics,—an influence which was second only to that of Maxwell." After an analysis of Ampère's and Grassmann's theories, he makes a critical comparison of the potential theories developed by Neu-

mann, Weber, and Helmholtz. The very general form of Helmholtz's theory appealed to him greatly, and he takes delight in showing how it contains as special cases most of the other theories proposed, including Maxwell's formulation of the results of Faraday's researches. Helmholtz's attempts to discriminate experimentally between various somewhat discordant view-points did not seem to him very conclusive, but his admiration for Hertz's genius knew no bounds. He lays particular emphasis on Hertz's zeal in following up every unexplained phenomenon to its source, mentioning in particular the discovery of the effect of ultra-violet light on the conductivity of the spark gap. His point of view throughout is that of the older British school of physicists, and it is evident that at this date the "ether" was very real to him.

During the five years following the completion of his doctor's thesis, Professor Bumstead's heavy teaching schedule left him little time for research. His interest in electrodynamics, however, was always keen, and in 1902 he published a short paper in which he showed how Maxwell's equations completely accounted for an anomaly in connection with reflection of electric waves which had been causing considerable discussion among experimentalists. If standing waves are set up on a pair of parallel guide wires terminating in a conducting plane at right angles to their length, the node in electric intensity found at the end of the wires is at a distance from the nearest node on the wire agreeing with the distances between other adjacent nodes. If, however, the conducting plane is removed, the loop to be expected at the free end of the wires is found to be at a distance from the nearest node somewhat less than a quarter wave-length. Bumstead showed that the introduction of a fictitious magnetic conductivity into Maxwell's equations established a close correspondence between this case and the well-understood arrangement in which the ends of the parallel conductors are united by a short connecting wire.

The year following the appearance of this paper, there fell on him the sad duty of writing the obituary of his friend and teacher, J. Willard Gibbs. His interest in and knowledge of mathematical physics enabled him to prepare an appreciation of the great physicist which could have been equalled by few of his contemporaries. Shortly

after, he edited, in collaboration with Dr. Van Name, Gibbs' collected works.

Bumstead's interest was greatly excited by J. J. Thomson's investigations of the properties of cathode rays and it was largely through his efforts that the successor of Maxwell and Rayleigh was persuaded to come to Yale to deliver the first Silliman lectures in May, 1903. While in New Haven Professor Thomson told him of the work being done at the Cavendish Laboratory on a radioactive gas found in water coming from deep levels, and suggested work of a similar nature at New Haven. This Bumstead carried out with the help of L. P. Wheeler. They found evidences of radioactivity not only in the gas driven off from water obtained from a well 1500 feet deep near New Milford, Conn., but also in that boiled off from surface water drawn from one of the New Haven city reservoirs. A comparison of the rate of decay of the soil-water gas with that of radium emanation showed the two to be identical. The rate of diffusion of the emanation through a porous plate was determined, and found to be about four times that of carbon dioxide. This led to an atomic weight of 180, which was, perhaps, the most reliable value which had been obtained up to that time, and, considering the difficulties of the experiment, surprisingly close to the value accepted today.

The winter 1904-5 Bumstead spent in England carrying on experimental work in the Cavendish Laboratory. This year's work led to the publication of two papers, of which the second, on the heating effects produced by Röntgen rays in metals, excited a great deal of interest. This investigation was undertaken at the time when the attention of the whole world was focused on the brilliant researches of Rutherford on atomic disintegration. Physicists were particularly interested in investigating the possibility of hastening radioactive disintegration by suitable external conditions, and in searching for new sources of radioactivity. However, every effort to control the rate of decay seemed to be in vain. From the lowest to the highest extremes of temperature, under all conditions of electromagnetic excitation, radioactive transformation went on at the same invariable rate. Bumstead's investigation consisted in measuring the heat produced in lead and zinc when Röntgen rays are equally absorbed in the two metals. His experiments seemed to lead to the very surprising result that heat developed in

lead is approximately double that produced in zinc. The only plausible explanation was that the rays effected a disintegration of the lead atoms through which they passed, liberating energy which was then converted into heat. This result, if true, would have constituted the first successful attempt to effect an artificial disintegration of the atom. Unfortunately, however, the subsequent work of Angerer and of Bumstead himself failed to confirm the results of the earlier experiment. By varying the conditions of the experiment Bumstead was able to show that the differential effect observed in the first instance was due to faulty heat-insulation of the metals under investigation.

In the meantime Bumstead had returned to New Haven to succeed Professor A. W. Wright as Professor of Physics in Yale College and Director of the Sloane Laboratory. He soon realized the inadequacy of the old Physics Laboratory, and it was largely as a result of his efforts that William D. Sloane and Henry T. Sloane of New York were persuaded to give to the University and to endow generously the present commodious building. All those who have benefited by the facilities and conveniences of the new laboratory are under a great debt of gratitude to Professor Bumstead for his many months of painstaking planning and careful supervision of the erection of the building. In this new laboratory were housed together, for the first time, both undergraduate departments of study in a single subject This union was the forerunner of the departmentalization which has been so prominent a feature of the recent University reorganization.

In 1905 appeared Einstein's epoch-making paper on the principle of relativity. Always interested in electromagnetic theories, Bumstead's mind was greatly stimulated by the new principle. In 1908 he published a critical comparison of the view-points of Einstein and Lorentz, and devised elegant methods of deducing some of the consequences of the theory. In particular, mention should be made of his derivation of the ratio of longitudinal to transverse mass from a simple consideration of the period of a moving torsion pendulum. In this paper he made some attempt to extend Einstein's method to gravitational problems, and pointed out clearly the fallacy of the oft-repeated assertion that a finite velocity of propagation

of gravitational force should produce a first order perturbation in planetary orbits.

While Bumstead was greatly impressed by the beauty and symmetry of Einstein's theory, the ether had such a real significance to him that he was never able to accept completely the view-point of the relativist. Furthermore, he doubted the value of the new principle in opening up unexplored fields of research. To him it seemed like a closed system, perfect but infertile. Hence Einstein's ultimate success in generalizing the principle, so as to make possible the application of the equivalence hypothesis to gravitational fields, appealed to him all the more as a great work of genius.

In 1911 Bumstead turned his attention to a study of the delta rays emitted by metals under the influence of alpha rays, which he continued for the three following years. Delta rays—so named by J. J. Thomson—are the slow-moving electrons detached from metallic atoms by the impact of the more massive alpha particles. The ionization curves obtained by Bumstead show all the characteristics of the Bragg curves for gases, but unlike the latter, the curves for different metals have very closely the same form. This led him to suspect that the delta rays come from a gas absorbed on the metal surface. An investigation of the velocities of the particles constituting the rays revealed the fact that some of them have velocities corresponding to a potential difference as great as 2000 volts. These swifter rays seem to be the primary result of impact of alpha rays, and to give rise to secondary slow-moving electrons when they collide with other atoms. The result of this experiment suggested to him that fast-moving electrons may also be produced when gaseous molecules are struck by alpha particles. To investigate this matter, he obtained from England an expansion apparatus made after C. T. R. Wilson's design. This apparatus he modified so as to enable him to work in hydrogen at a pressure of 100 mm., and with it he obtained a number of photographs of alpha ray tracks, which showed very clearly electronic trails radiating from the column. These trails are undoubtedly due to swift delta rays.

In addition to the papers published under his own name, Professor Bumstead supplied the underlying ideas and much of the motive force responsible for the great

majority of doctors' theses in physics coming from Yale during the last fifteen years. He was always generous in giving his time and ideas to others, and never asked the students who worked under him to share with him the credit of authorship.

Recognition of his ability as a scientist has come from many sources. Long a member of the American Physical Society, he has been its president and an editor of its organ of publication, the *Physical Review*. As Vice President of the American Association for the Advancement of Science, he delivered the annual address at the meeting in Pittsburgh in December 1917, choosing for his title "Present Tendencies in Theoretical Physics." In 1913 he was elected a member of the National Academy of Sciences, the highest honor which can come to any scientist from an American institution. He was a fellow of the American Academy of Arts and Sciences, and a member of the American Philosophical Society and of the Connecticut Academy of Arts and Sciences. The University of Toronto conferred on him the honorary degree of Doctor of Science the June preceding his death.

Not only was Bumstead's advice always in demand on the part of his scientific confrères, but it was frequently sought by those whose chief interests lay along the lines of the so-called humanities. As an example may be cited Henry Adams' request for a critical opinion of those chapters of "The Degradation of the Democratic Dogma" which contained the author's bold excursion on the scientific method. Bumstead pointed out the dimensional difficulties involved in applying the "law of squares" to historical phases, and repeated his criticism to Brooks Adams when the latter was preparing his brother's manuscript for publication. In this instance, however, science lost that history might be justified.

With the entrance of the United States into the World War, Bumstead placed all his time and ability at the service of his country. He was a member of the national committee appointed to examine the merits of proposed anti-submarine devices, and he took an active interest in the experimental development of such devices which was carried on at New London. In February, 1918, he went to London as Scientific Attaché of the American Embassy. There his tact and wide acquaintance among men of science in Great Britain enabled him to perform a service

of inestimable value as a clearing house for scientific information. War today is dependent on science in a degree never known before, and innumerable researches have to be carried on with expedition and without unnecessary duplication. Hence the vital importance to each country of prompt and accurate information regarding the work already completed by its allies.

On his return to New Haven a few months after the Armistice, Bumstead found the University in the midst of reorganization. His remarkable power of coördinating the divergent view-points of others and his excellent judgment made him much in demand as a member of the committees which were moulding the future Yale. He gave freely of his time and his strength, in spite of his desire for the opportunity to devote himself to a life of quiet study and research. Finally came the call to succeed Dr. Angell—Yale's president-elect—as chairman of the National Research Council. The occupant of this position is changed annually, so his acceptance would necessitate only a single year's leave of absence from Yale, and he did not feel justified in refusing the opportunity of a wider service. His executive ability and power of drawing the best out of others made his success in his new position a certainty.

He was not, however, destined to live out his term of office. The day after Christmas, 1920, he took train for Chicago to attend the annual meeting of the American Physical Society. To his many friends who talked with him there, he appeared to be at the height of mental and bodily vigor. On Wednesday evening of this week he attended a meeting of a committee of which the writer happens to be a member, and contributed his keen analysis to the discussion until almost midnight. Friday he started on the return trip to Washington. Saturday morning he was found lifeless in his berth.

Professor Bumstead's power as a teacher was even greater than his ability as a scientist. Since the death of Professor Gibbs, his courses in Electrodynamics and Electromagnetic Theory of Light have been the inspiration of the graduate work in physics at Yale. He has never been too busy or too hurried to spend an hour discussing a knotty problem with a member of his class. Not only has he given freely of his time, but on occasion he has even extended financial aid to needy graduate students. His illuminating discussions at the meetings

of the Physics Club were eagerly looked forward to by both students and colleagues.

Eminent as a scientist, inspiring as a teacher, he was peerless as a man. Always cheerful and ready to lend a helping hand to others, he was loved alike by students, colleagues, and everyone who had the good fortune to come in contact with him. His high ideals, in human relationship as well as in scientific attainment, have had a profound influence in moulding the characters of the young men whom he has trained. His body may turn to dust, but his soul lives on in the hearts and minds of those who have been left behind to carry on his work.

LEIGH PAGE.

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Art. XXXV.—*Two New Fossil Carnivora;* by Malcolm Rutherford Thorpe.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

Pliocyon marshi, gen. et sp. nov.

(Figs. 1-3.)

Holotype, Cat. No. 10043, Y. P. M. Right lower jaw. Pliocene. (Rattlesnake), near Cottonwood, John Day Valley, Oregon. Collected in 1874 by L. S. Davis.

Distinctive characters.—Dental formula I_2, C_1, P_2, M_2; ramus long and slender; angle heavy and rugose; P_1 small and adjacent to C; P_4 with prominent posterior tubercle and heel; M_1 very large, with robust protoconid, prominent metaconid, and low hypoconid medially situated on the talonid; paraconid large and high. M_2 long and stout, gradually decreasing posteriorly in width; symphysis short; canines close together; mental foramen beneath anterior root of P_4 and another below the anterior part of the diastema behind P_1; I_3 in front of C; nearest part of C alveolus but 4 mm. from symphysis.

Dimensions.

	mm.
Ramus, length, C alveolus to condyle, inc.	125
Tooth row, length, C alveolus to M_2 alveolus, inc.	79
M_2 alveolus, length	14.5
M_1, length	22.5
Width	10
P_4, length	13.8
Width	8
C alveolus, ant.-post. diameter	13.5
Transverse diameter	8
Depth of ramus below protoconid of M_1	26
Depth of ramus below middle of Pm diastema	20.5

Geologic horizon.—This specimen was collected about a mile west of Cottonwood, on the East Fork of the John Day River. The enclosing matrix was soft tuff, lying between the basal conglomerate and the capping rim rock of rhyolite, about 3 feet below the lower edge of the latter according to a letter written to Professor Marsh by L. S. Davis, dated Camp Watson, March 15, 1874. This formation is the Rattlesnake of Merriam, and is of middle

Pliocene age. The bone varies in color from light grey to slate, while the teeth are dark blue.

Relationships.—No specimen comparable to this has been described or reported from North America. In fact, it resembles more closely *Simocyon primigenius* Roth and Wagner than any other form, a fact first recognized by Professor Lull. *Simocyon primigenius* is Lower Pliocene in age, and comes from the Pikermi beds, near Athens, Greece.

This European species differs from *Pliocyon marshi* in having (1) but one lower premolar, P_4; (2) a longer and more robust ramus; (3) three incisors; (4) a much wider canine with nearly the same antero-posterior diameter; (5) a greater distance between canines; (6) anterior mental foramen below the middle of the diastema anterior to P_4; (7) internal, mandibular foramen much lower and farther from M_1; (8) a longer symphysis; (9) a much greater outward curvature of the ramus; (10) a much greater degree of outward trend below the tooth row; and several other less important differences.

Fig. 1.—*Pliocyon marshi*, gen. et sp. nov. Holotype. External lateral view. $\times$ 4/5.

Pliocyon marshi differs from *Simocyon diaphorus* Kaup, on the other hand, in having (1) no P_2 and P_3; (2) a smaller and lower metaconid on M_1, and a larger hypoconid; (3) a much shallower cleft between the para- and protoconid of M_1; (4) a longer and higher P_4, but with less prominent basal heel; (5) M_2 placed nearly level with respect to the tooth row, instead of rising steeply posteriorly; (6) a shorter horizontal ramus; (7) anterior mental foramina closer together, with the anterior one higher; and (8) a somewhat shorter but wider M_1.

The two species, *S. primigenius* and *S. diaphorus,* are so unlike that I doubt the validity of this classification. In fact, it seems that *Pliocyon marshi* is closer to *S. primigenius* than is *S. diaphorus,* but I do not believe that this new form should be considered as a species of *Simocyon. Pliocyon* is of later age than *S. primigenius,* but in some

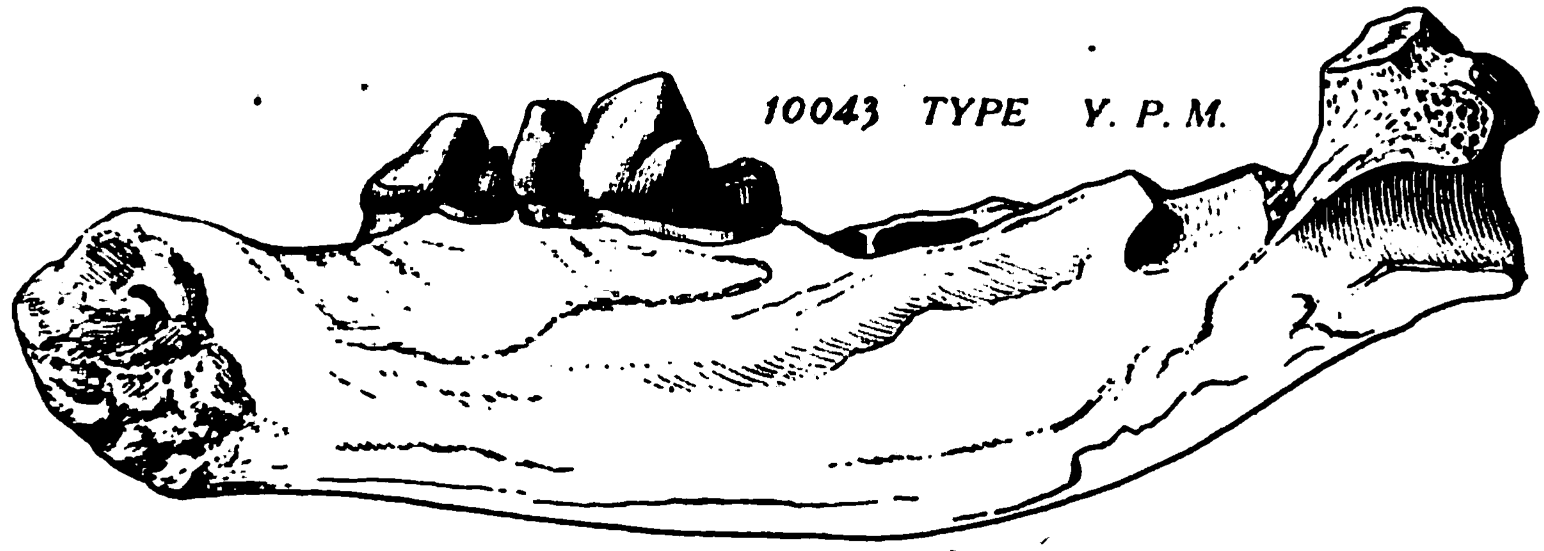

FIG. 2.—*Pliocyon marshi,* gen. et sp. nov. Holotype. Internal lateral view. × 4/5.

respects it seems to show less advanced characters. Both were brachycephalic forms and had, of course, reached a high degree of specialization. The exact taxonomic position of the new North American form can not be determined on the presence of this one ramus. Apparently, however, we can safely conclude that *Pliocyon* is the New World representative of the Pikermi *Simocyon.*

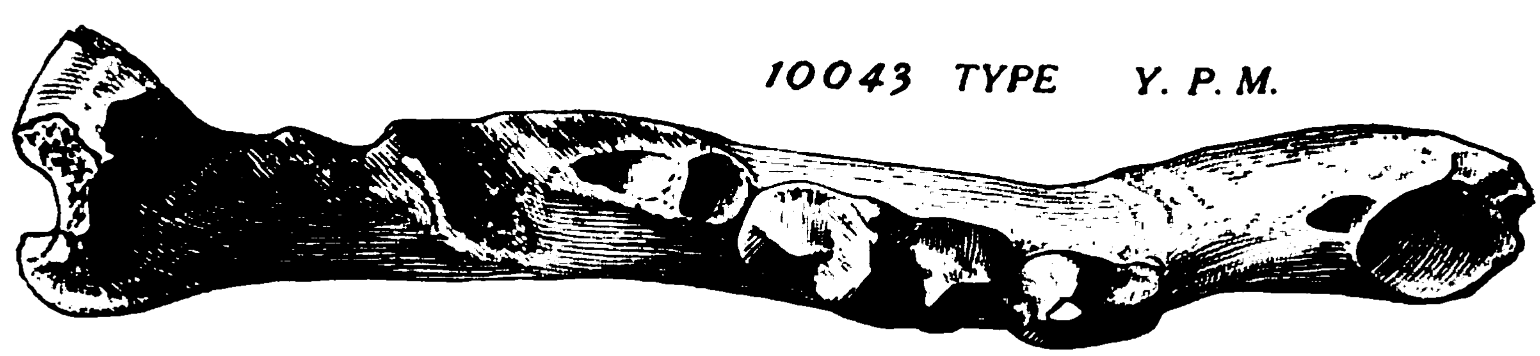

FIG. 3.—*Pliocyon marshi,* gen. et sp. nov. Holotype. Superior view. × 4/5.

Oligobunis Cope.

When Cope described this genus in 1881, he considered it ancestral to *Icticyon* Lund, and as allied to the Canidæ. The type, *O. crassivultus,* is from the John Day beds. In 1907 Matthew reëxamined the type and referred it to the Mustelidæ.

The dental formula is $I\frac{3}{3}$, $C\frac{1}{1}$, $P\frac{4-3}{4}$, $M\frac{2}{2}$. Cope did not know of the existence of M^2 and used its supposed absence in part as a generic distinction from *Icticyon.* The type,

No. 6903, A. M. N. H., consists of the anterior half of a skull with rami, about the size of *Taxidea americana.* The muzzle is short and stout, lacking the constriction anterior to P^4, common to the Canidæ. The zygomatic fossa is short; the orbits small, and the infra-orbital foramen above the interval between P^3 and P^4.

The rami are robust, with deep masseteric fossæ. The condyles are on a line with M_1, while the coronoid is wide and high. The canine is stout, and the premolars short and massive. P^1 is very small; P^2 but slightly ovate; P^3 somewhat obliquely placed; P^4 large, with a well developed deuterocone, and the blades separated by a distinct notch. Matthew says of M^1 (p. 193) that it "is reduced antero-posteriorly and much extended transversely, the paracone nearly median, metacone vestigial and parastyle much extended, protocone compressed, and, as in all primitive Mustelines, it lacks the broad flange characteristic of the modern Mustelidæ." M^2 is small and oval.

The inferior premolars are slightly spaced and P_1 is very diminutive. M_1 has a rather large heel and a well developed metaconid, while M_2 is small and oval, with the meta- and hypoconid of nearly equal height.

Oligobunis darbyi, sp. nov.

(Figs. 4, 5.)

Holotype, Cat. No. 10272, Y. P. M. Skull and jaws. Lower Miocene (Monroe Creek beds—lower Harrison), Pine Ridge, 12 miles north of Harrison, Sioux Co., Nebraska, on the Warbonnet ranch, in Sec. 2, T 32 N., R 56 W. Collected in 1914 by Mr. Fred Darby, after whom the species is named.

Specific characters.—The skull is approximately the same size as that of *Icticyon venaticus,* the South American bush dog (Goldman 1920, p. 149), or considerably smaller than that of *O. crassivultus.* It is strongly dolichocephalic, with a very short muzzle. There is a large infra-orbital foramen above the posterior margin of P^3, the superior contour slopes gently both ways from the junction of the temporal ridges, the length of the zygomatic fossa is equivalent to about one third of the total skull length, the sagittal crest is barely marked, and the zygomatic arches are very slender.

The cranial and basicranial areas of this genus have been unknown heretofore. The bullæ are partly broken

away, although there is sufficient evidence to show that they were moderately inflated and oval in outline. The foramina correspond very closely in position to those of *Megalictis ferox* Matthew (1907, p. 197). The condylar foramen is exceedingly small; the foramen lacerum posterius and the carotid canal are not clearly defined but they were located internally and about medially of the bullæ; the stylomastoid foramen is rather large and the postglenoid foramen small, this latter lying about midway between the external auditory meatus and the base of the postglenoid process; the foramen ovale is moderately large and located internally from about on a line with the postglenoid tubercle; the foramen lacerum medius is likewise large and situated antero-internally from the

FIG. 4.—*Oligobunis darbyi*, sp. nov. Holotype. Right lateral view. Nat. size.

bulla. The external auditory meatus is quite large and directed forward. The postglenoid process is wide and its lower extremity internally curves downward and forward to a marked degree. The mastoid process is robust and heavy, directed much more outward than downward, while the paramastoid is situated considerably more posteriorly and extends somewhat backward but chiefly downward. The basicranial axis is nearly straight; the pterygoid processes are thin and quite prominent, while the palate was undoubtedly nearly flat.

The canines are stout and of median length. P^1 is small and has no diastema on either side. The other

teeth are not distinctive, except M^2, which is very small, oval, and situated about medially with respect to M^1. The inferior canine is recurved and the tooth row is continuous, with no diastemata. The ramus is slender; masseteric fossa very deep and large; angle prominent; and coronoid wide, thin, and high. The condyle is situated on a line with the dental series. There are three mental foramina in the same horizontal line.

FIG. 5.—*Oligobunis darbyi*, sp. nov. Holotype. Inferior view, right half of skull. Nat. size.

Dimensions.

	mm.
Skull, length, occip. condyles to canine, inc.	96
Bizygomatic diameter	47
Diameter, post-orbital constriction	19.5
Superior dental series, inc. C, length	40
Superior molar series, length	8.2
Superior premolar series, length	25.2
Ramus, length, inc. canine	66
Depth, coronoid to angle	28.5
Depth below middle of M_1	13
Inferior molar series, length	15
Inferior premolar series, length	21.5

In so far as comparable parts are present of both the type of the genus, *O. crassivultus* Cope, and *O. darbyi*, sp. nov., the latter differs chiefly in (1) smaller size, (2) much greater degree of dolichocephaly, (3) a continuous inferior and superior tooth row, (4) larger size of infra-orbital foramen, (5) different size and shape of masseteric fossa, (6) different proportions of anterior zygomatic pedicle, (7) much less prominent angle of ramus, (8) considerably smaller deuterocone of P^4, and (9) different geographical locality and geological horizon. Many minor differences may also be noted.

The new species differs from the type of *O. lepidus*

Matthew, No. 12865, A. M. N. H., in (1) larger size and (2) different proportions. The paratypes of the latter species, Nos. 12866 and 12867, are figured, but not the type. In comparison with the paratypes, *O. darbyi*, sp. nov., differs in (1) somewhat larger size, (2) possession of P^1, (3) greater crowding of the premolars, (4) much larger size of P_1, (5) smaller size and different shape of M^2, (6) less curvature of the inferior tooth row, (7) greater degree of recurving of C_1, (8) straighter inferior outline of the ramus, and (9) greater depth of ramus below the tooth row.

These paratypes Matthew designated in his table of measurements as a new variety, *robustior*, although I think that additional material would elevate them to the rank of a new species, more advanced in development than any of the others. Another paratype of the same species, No. 12868, may well be a male of *O. lepidus*, as it agrees with the type except in being of larger size.

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ART. XXXVI.—*A New Harmonic Analyzer;* by WARREN MASON.

Since Fourier first published his "Theory Analytique de la Chaleur," there have been a number of machines called harmonic analyzers invented for the purpose of evaluating his integrals mechanically. Some of these have been in use for over a hundred years, so the only reason for describing another one would be that it is simpler to make or more accurate than other machines. The instrument described in this paper has about the same degree of accuracy as any except the Henrici analyzer, but its main point of interest is that it can be made by anyone without the use of complicated machinery.

A periodic curve can be represented by a series of the kind

$$y = A + A_1 \sin a + B_1 \cos a + A_2 \sin 2a + B_2 \cos 2a + \ldots$$

where A is a constant equal to the algebraic sum of the area of the two loops forming one wave length, and A_1, B_1, A_2, B_2, etc., constants denoting the maximum heights of the respective harmonics. Fourier has shown that the value of any constant A_n is given by the integral

$$A_n = \frac{1}{\pi}\int_0^{2\pi} y \sin n\,a\,d\,a,$$

while the value of the constant B_n is given by

$$B_n = \frac{1}{\pi}\int_0^{2\pi} y \cos n\,a\,d\,a.$$

As in the case of most harmonic analyzers, this machine evaluates the above integrals by tracing an area proportional to the value of the expression. Therefore we may at once write

$$K\,A = A_n \qquad (1)$$

where A is the equivalent area referred to above, and K a constant of proportionality. Substituting the integrals for the above terms, we have

$$K\int_{x_1'}^{x_2'} (y_2' - y_1')\,dx' = \frac{1}{\pi}\int_0^{2\pi} y \sin n\,a\,d\,a. \qquad (2)$$

x, and y in the following equations refer to the coordinates of the wave form with reference to axes at the origin of, and along the axis of, the wave form, while x', y', which

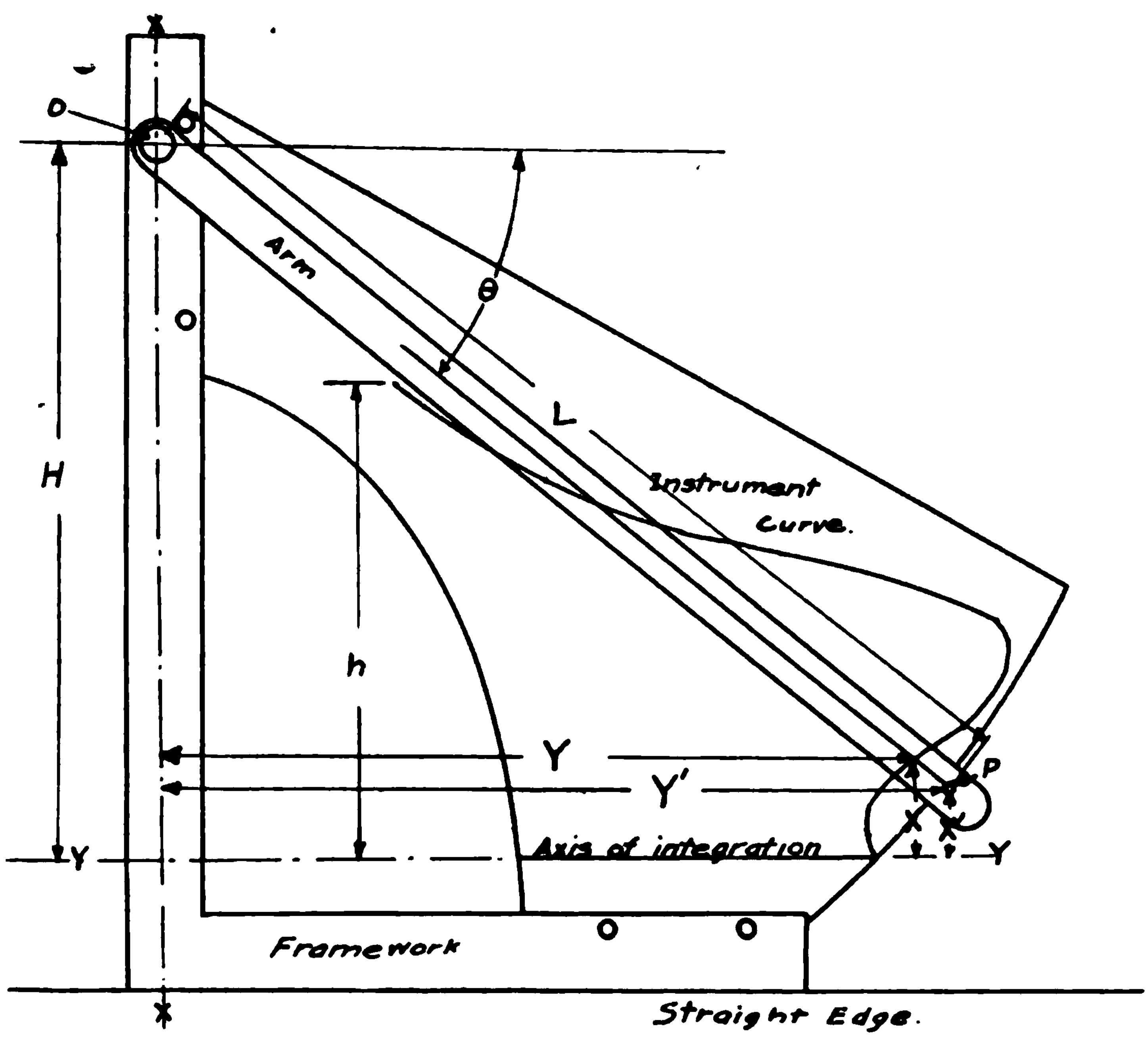
are the coordinates of the derived area, refer to the same axes. All machines of this type have a definite wave length to analyze, which we will designate by the letter h. α, then in terms of h and x, is

$$\frac{\alpha}{2\pi} = \frac{x}{h} \text{ or } \alpha = \frac{2\pi x}{h}. \quad (3)$$

Substituting this value of α in equation (2), the expression becomes

$$K\int_{x_1'}^{x_2'} (y_2' - y_1')\, dx' = \frac{2}{h}\int_0^{2\pi} y \sin\frac{2n\pi x}{h}\, dx. \quad (4)$$

FIG. 1.



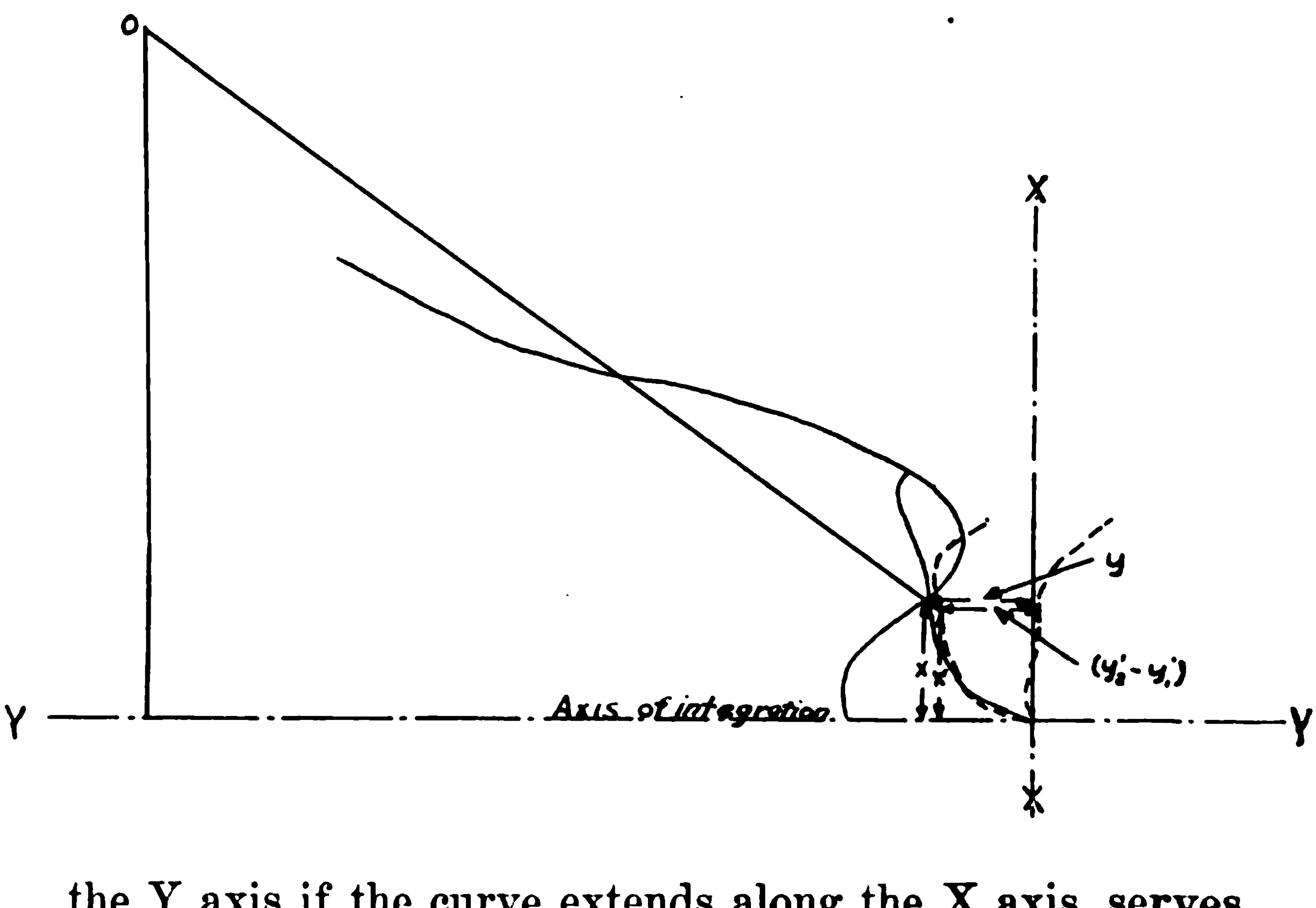
Differentiating this equation to get rid of the limits

$$K\,(y_2' - y_1')\, dx' = \frac{2}{h}\, y \sin\frac{2n\pi x}{h}\, dx. \quad (5)$$

The machine by which we propose to evaluate the Fourier integrals consists of a framework, an arm, a curve, and a straight edge. The framework is an L-shaped piece of wood or metal, grooved on the bottom to allow a zylonite curve to slip into place when the framework is placed over it. Lugs placed in the framework

fit into holes on the curve and hold it in place. A series of transparent zylonite pieces, one for each sine or cosine harmonic, on which particular curves have been engraved, are the instrument curves referred to. An arm, made partly of metal, and partly of a zylonite strip on which a straight line has been engraved, is fastened to the framework by means of a pivot O. Fig. 1 illustrates this construction. At the end of this arm a small hole P is bored, in which either a pencil point or the tracing point of a planimeter may be placed. A straight edge fastened to the board on the axis of integration, which is always

Fig. 2.



the Y axis if the curve extends along the X axis, serves as a guide for the machine. The essential operation consists in tracing the wave form to be analyzed with the intersection of the arm and the instrument curve, and at the same time drawing the derived area by means of a pencil point placed in the tracing point of the analyzer. It can be seen from fig. 2, that any ordinate of the wave form is exactly reproduced in the derived area, for when x is constant, the arm is fixed, and draws one ordinate as long as the other. Therefore, since $(y_2'-y_1')=y$ in equation (5), these factors can be cancelled out leaving the equation

$$K\, dx' = \frac{2}{h} \sin \frac{2 n \pi x}{h} dx. \qquad (6)$$

Integrating this we have

$$K\, x' = \frac{1}{n\pi} \cos \frac{2 n \pi x}{h} + C. \qquad (7)$$

From fig. 2 is can be seen that when

$$x = 0,\ x' = 0,\ \text{so } C = \frac{1}{n\pi}.$$

Substituting this value for C in equation (7)

$$x' = \frac{1}{n\pi K} \left(1 - \cos \frac{2 n \pi x}{h}\right). \qquad (8)$$

This equation merely states that if the instrument curve is so constructed that the abscissæ of the tracing point and the abscissæ of the curve satisfy equation (8), the tracing point of the instrument will draw an area proportional to the constant desired. To obtain this curve we will refer again to fig. 1. θ is the angle the arm makes with a horizontal line, L the distance between the pivot and the tracing point, H the distance of the pivot above the axis of integration of the machine, X, Y, the coordinates of the curve with reference to an axis along the axis of integration of the machine, and to one perpendicular to it through the point O, and X′, Y′, the coordinates of the tracing point with reference to the same axes. It will be noticed that X and x are measured from the same axis and when the machine is in operation have simultaneous values; the same may also be said of X′ and x'. No similar relations exist between Y and y or Y′ and y', but as these terms do not appear in the essential equation, this does not matter. From the figure

$$\sin \theta = \frac{H - X'}{L} \text{ and } Y = \frac{H - X}{\tan \theta}.$$

Since from equation (8)

$$x' \text{ or } X' = \frac{1}{n K \pi} \left(1 - \cos \frac{2 n \pi x}{h}\right),$$

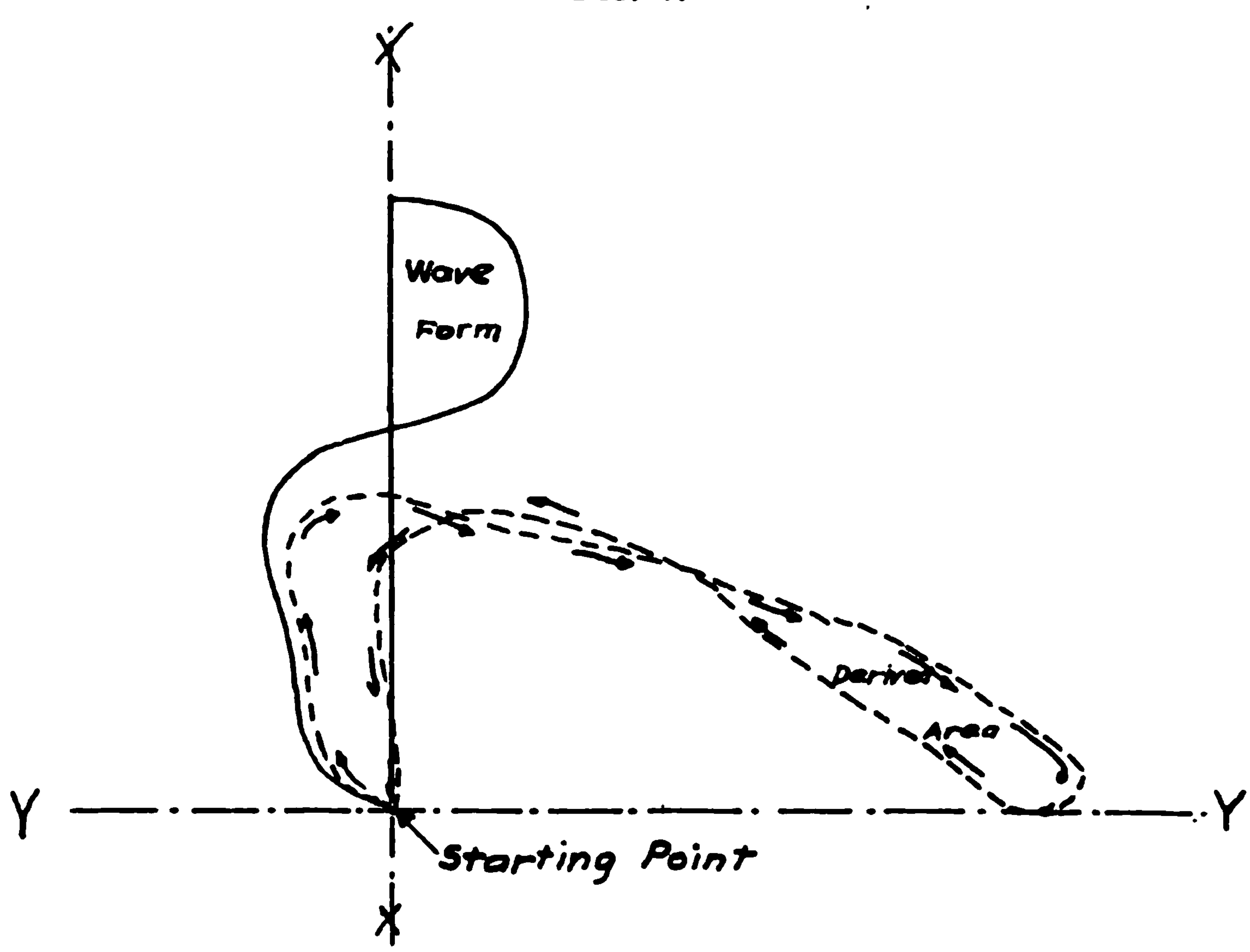
by assuming values of x or X, Y can be calculated and the curve fully determined.

The only point not determined is what value to use for K. The smaller this value becomes, the smaller the absolute error will be, so it will pay us to use as small a value

as possible. From practical considerations this value will be $K = \frac{4}{3h}$ for any smaller value than this will cause the curve to extend outside of the tracing point. H is taken as $3/2\ h$, for if it is taken any smaller, the results will not be very accurate, while if taken much larger, the machine tends to become unwieldy.

A cosine curve may be obtained in a similar manner, going through the same set of equations and replacing the sin by the cosin.

FIG. 3.



If only the odd harmonics are to be found, then it is necessary to analyze only one loop of the wave form. The integral to be evaluated is

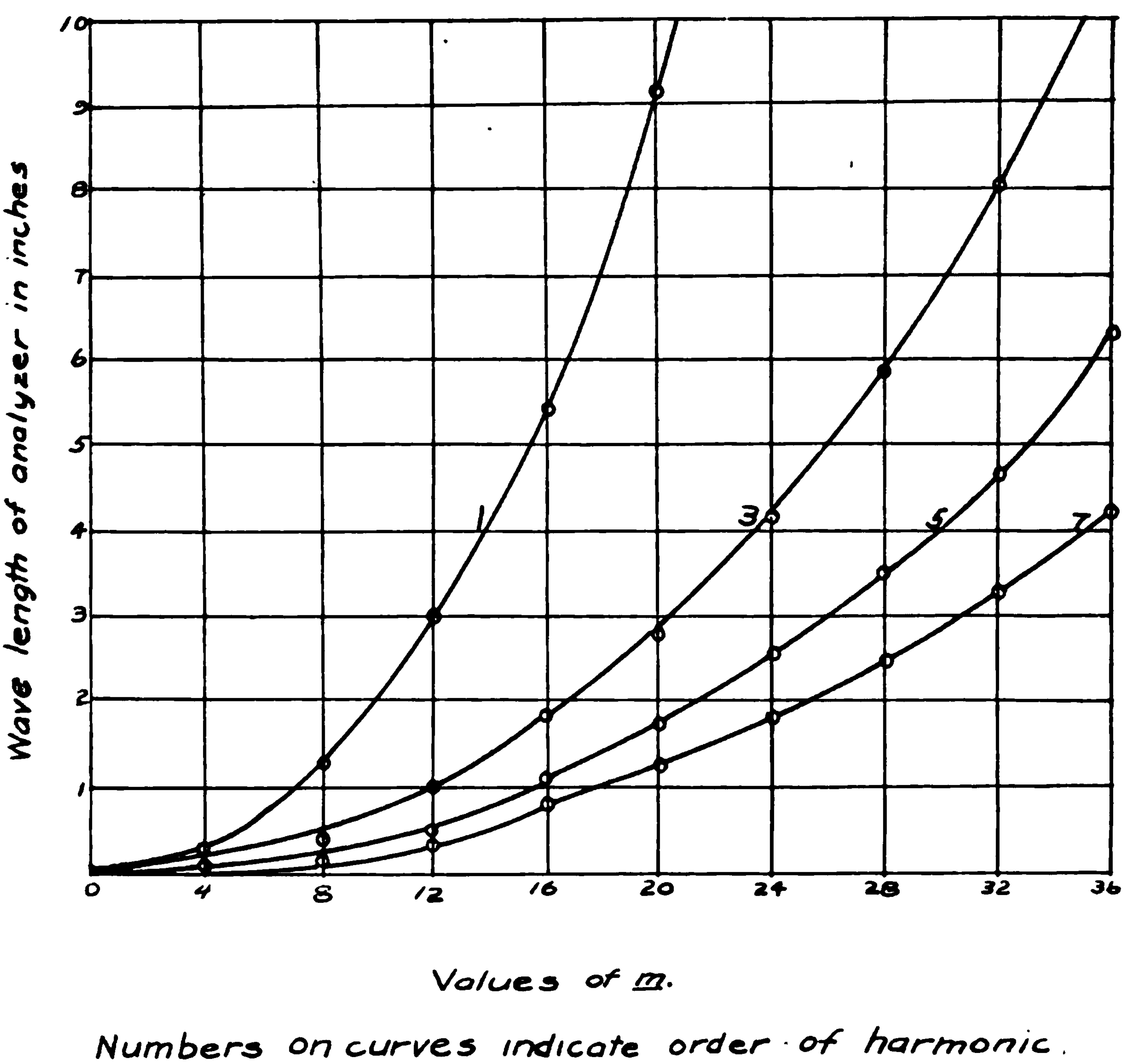
$$A_n = \frac{2}{\pi}\int_0^\pi y \sin n\, a\, d\, a,$$

and if this is substituted in equation (1), a similar set of instrument curves may be found for this type of machine. As only one loop has to be analyzed, the instrument will be only half as large.

As stated before, the essential operation consists in tracing the wave form with the intersection of the arm and instrument curve, while at the same time the derived area is drawn by the tracing point. It should be espe-

cially noticed that the axis of the wave form must be traced as well as the wave form itself, for otherwise no closed area would be obtained. The derived area will consist of a number of loops, the number depending on the harmonic analyzed for, and the size and shape of the wave form. Fig. 3 shows a sample wave form and derived area for the first sin harmonic. Every time the lines cross over the sign of the area changes. On all

FIG. 4.



polar or rolling planimeter positive area is that area which is measured in a clockwise direction, while if the direction of rotation is reversed, the value recorded has a negative sign. This fact can be utilized in the summing up of the positive and negative areas at one reading, for if the tracing point of the planimeter follows the tracing point of the analyzer in the exact path traced by it, the tracing point of the planimeter will go around the positive loops in one direction and the negative loops in another.

For this reason it is not necessary to draw out the equivalent area, but only necessary to place the tracing point of the planimeter in the tracing point of the analyzer, trace the figure, and read the planimeter directly. As the first sin or cosin loops will always be positive in area unless the ordinates themselves are negative, the tracing point of the planimeter should start at the end of this first loop, and follow the upper side around the successive loops back to the starting point. The arrows in fig. 3 illustrate this principle as applied to a derived area from a first sin harmonic analyzer. The sign of the resulting reading will tell whether the harmonic is positive or negative.

The absolute error measured in inches of result for any harmonic of this machine is given by the formula

$$E = \frac{.01\ B}{h},$$

where B is the maximum ordinate of the wave form to be analyzed, and h the wave length of the analyzer. Fig. 4 shows a comparison of the errors for the analyzer and for a computation method, using as a basis of comparison a constant ordinate wave form, which is nearly the only form in which errors by a computation method can be directly calculated. The lines on the figure represent conditions of equal accuracy. M in the figure represents the number of ordinates per wave length used in calculating the constants, while h represents the wave lengths of the analyzer used. This figure shows that the analyzer is more accurate, especially for the higher harmonics.

Lawrence, Kansas.

ART. XXXVII.—*Orientite, a new hydrous Silicate of Manganese and Calcium from Cuba;*[1] by D. F. HEWETT[2] and EARL V. SHANNON.[3]

CONTENTS.

Introduction.

Introduction.—In the course of the examination of some manganese deposits in Oriente Province, Cuba, during March and April, 1920, a crystallized silicate of manganese and calcium was discovered by D. F. Hewett. After preliminary tests, specimens were sent to E. V. Shannon, who determined that the mineral was a hydrous silicate of manganese and calcium and represented a new species. In the following statement, the crystallographic, optical and chemical studies have been made by Shannon and those with reference to mode of occurrence and genesis by Hewett.

As the mineral is known to occur in two localities in Oriente Province, where many manganese deposits are found,[4] and it may be widespread in the region, it is appropriate that the geographic relation be perpetuated in the name *orientite.*

Part I.

Mode of Occurrence.—The province of Oriente roughly coincides with a broad structural trough in the rocks,

[1] Published by permission of the Director of the U. S. Geological Survey and the Secretary of the Smithsonian Institution.

[2] Geologist, U. S. Geological Survey.

[3] Assistant Curator, Department of Geology, U. S. National Museum.

[4] Hayes, C. W., Vaughan, T. W., Spencer, A. C., Report on a geological reconnaissance of Cuba made under direction of Gen. Leonard Wood, 1901.
Burchard, E. F., Manganese-Ore Deposits in Cuba, Trans. Am. Inst. Min. & Met. Eng., vol. 63, p. 51-104, 1920.

which pitches to the west. The southern limit of the trough is the igneous complex of the Sierra Maestra; the northern limit is a group of low ranges near the north coast, largely made up of serpentine. The trough comprises a great thickness, possibly 8,000 to 10,000 feet, of bedded volcanic breccias, and tuffs with andesite and latite flows, and limestone. On the southern limb of the trough tuffs, breccias and flows constitute more than 95 per cent of the lower 2,000 or 3,000 feet but the proportion of limestone is larger than that of the igneous rocks in the upper 2,000 feet or more. The lower course of the Cauto River approximately follows the trough. The manganese deposits occur over a wide stratigraphic range in the middle part of the section, to which an upper Eocene age has been tentatively assigned.

The minerals of the manganese deposits of Cuba, in order of abundance, are psilomelane, both hard and soft varieties, manganite, pyrolusite, wad, neotocite and orientite.

The accessory minerals include "bayate" or ferruginous jasper, glauconite (?), barite, quartz, calcite and several zeolites. Although a few bodies of manganese oxides occur in limestone or the clay resulting from its decay, most of them replace fine tuff or volcanic ash. They assume many forms, dependent upon local structural features.

Orientite was first found in a group of deposits on the Costa, Manuel and Vicente claims, 6 miles south of Bueycito and 20 miles southwest of Bayamo. Later it was found in material from the Santa Rosa prospect, near Banes, north of Antilla. An amorphous hydrous silicate of manganese which is probably neotocite, was found in material from the Abundancia mine at Manganeso. Material encountered in several other deposits (Isabelita, Ponupo, Llave) indicates that neotocite, and possibly orientite, was once present but has been destroyed by weathering. Neither mineral was definitely recognized, however, in the Jutinicum, Dos Bocas and Baire districts, which were also examined.

Orientite was first recognized as minute reddish-brown crystals that lined drusy cavities in Open Cut No. 8 on the Costa claim, and similar material was later found at many other open cuts on the Costa, Manuel and Vicente claims. Later, when thin sections of material from other openings were studied, it was found that orientite was widespread,

even where it could not be distinguished in hand specimens.

The Costa, Manuel and Vicente claims,[5] aggregating 403 hectares (995 acres), cover an area of alternating bedded tuffs and breccias of latitic andesitic type, latite flows and thin limestones. These rocks dip northward at 10° to 15° and are broken by two systems of faults. Several andesite dikes occur in faults. The fine tuffs that have been studied under the microscope contain oligoclase, orthoclase, diopside, hornblende, and rock fragments which are largely glass, here and there reddish in color, due to included ferric oxide grains and containing laths of feldspar. The matrix of the tuffs contains glass which is generally altered near the ore bodies. The ore-bodies of these claims contain psilomelane, manganite, pyrolusite and orientite and are wholly in the fine tuffs. Where coarse breccias are adjacent to ore-bodies, some manganese oxides may occur in the fine matrix of the breccias. The manganese oxides and silicate were deposited in the tuffs largely by replacing the glassy portion of the rock fragments.

Associated Minerals.—Psilomelane is present in most of the deposits and both the variety, harder as well as that softer than a steel knife, were recognized. It forms fibrous masses that commonly range from 1 to 50 mm. in maximum size. Some plumose aggregates having similar associations are probably manganite. Commonly, these masses occur in layers roughly parallel to layers of tuff; in some places they are sporadically distributed through relatively unaltered tuffs. The available thin sections of the larger masses indicate that the manganese minerals have locally completely replaced all of the minerals and rock fragments that previously were present, feldspar, diopside and glass. In some sections of material that shows disseminated minute particles of psilomelane, largely found on the borders of the deposits, the manganese minerals fill the space between the residual feldspar grains, which clearly have survived the process of replacement. In other thin sections, there are minute opaque grains in the crystals and other particles of orientite (fig. 1) that are probably psilomelane. Psilomelane and the plumose manganite were clearly the first minerals to be deposited in the tuffs. Veinlets of orientite in fig. 2

[5] Burchard, E. F., loc. cit., p. 80.

fill cracks that cut across plumose manganite and are clearly later than that mineral.

In some places manganite forms plumose aggregates

FIG. 1.—Black, manganese oxide (psilomelane?); gray, crystals (o), orientite; white (c), calcite. × 25 diameters.
Oxides form nuclei in orientite; druses are filled with calcite. Mottled appearance of orientite is due to its high index of refraction.
Open cut. No. 20, Costa Claim, 6 miles south of Bueycito, Oriente, Cuba.

that have associations similar to psilomelane and is therefore probably contemporaneous with it. It also forms short wedge-shaped prisms 1 to 2 mm. long, which occur

FIG. 2.—Black, plumose aggregates of manganite (?); gray (o), orientite; white (op), opal (?); white (s), open space. × 6 diameters.
Veinlets of orientite cut and are later than the aggregates of manganite.
Open cut No. 8, Costa Claim, 6 miles south of Bueycito, Oriente, Cuba.

in druses, and fills veinlets which commonly rest upon or cut the psilomelane and orientite, and is, therefore, later than these minerals. It has been impossible to accurately discriminate between manganite and pyrolusite; the hardness of the crystals corresponds with that of manganite, and water was given off when numerous specimens were heated in a closed tube. On the other hand, it is possible to sort out from the material from most of the deposits, a portion that contains considerable crystalline material, which is shown by analysis to contain 90 to 92 per cent MnO_2, and is therefore undoubtedly pyrolusite.[6] Wad is sparingly distributed in the deposits, but appears to be a product of recent weathering.

Orientite assumes several forms, depending apparently on whether it is abundant or scarce. Where it is abundant in the Bueycito region, myriads of small reddish-brown prismatic crystals cover drusy cavities (fig. 1) in psilomelane. Some specimens that appear to be made up largely of psilomelane, are shown by thin sections and polished surfaces to be an intricate mixture of psilomelane and orientite (fig. 2). In such mixtures, the orientite grains are made up of aggregates of minute tabular crystals. Elsewhere in the neighborhood there are large bodies of tuffs that appear to be impregnated with disseminated psilomelane and contain 5 to 20 per cent manganese. A number of thin sections of such material shows that orientite is universally associated with the manganese oxide, but like it forms small grains in the matrix of the tuff, or replaces the glass of the rock fragments, leaving the included feldspars unaltered (fig. 3). Some sections in which the feldspars are quite fresh, show diopside crystals which are surrounded by a border of orientite. Such relations suggest that the diopside is more readily replaced than the feldspar.

Several thin sections of material from the Bueycito region show orientite pseudomorphs of foraminifera imbedded in manganese oxide (psilomelane ?) (fig. 4.). It would appear that this selective replacement of the foraminifera by the silicate of manganese and calcium is due to the high calcium content of the fossils.

An amorphous silicate (neotocite ? see p. 492) is present in material from Vicente Open Cut No. 15 near Bueycito, from the Abundancia Mine near Manganeso, and the

[6] Watson, T. L., Pyrolusite in Virginia, Jour. Wash. Acad. Sci., vol. 8, p. 550-560, 1918.

Santa Rosa prospect near Banes. Thin sections of material from the Vicente claim show irregular areas of

FIG. 3.—Black, manganese oxide; dark gray (o), orientite; light gray (p), plagioclase crystals; white (s), open space. × 25 diameters.
The alignment of the fresh plagioclase laths in the grains of orientite indicates flow structure in original glass, now replaced by orientite.
Open cut No. 8, Costa Claim, 6 miles south of Bueycito, Oriente, Cuba.

a clear light brown amorphous mineral in which there are minute rosettes of orientite crystals. It was first thought that the amorphous mineral was a variety of orientite, but

FIG. 4.—Black, manganese oxide; gray (o), orientite pseudomorphs of foraminifera; white (s), open space. × 25 diameters.
Foraminifera (calcite) replaced by orientite; remainder of rock largely replaced by manganese oxide.
Open cut No. 8, Costa Claim, 6 miles south of Bueycito, Oriente, Cuba.

the analyses which follow show that although it is a hydrous silicate of manganese, it is deficient in lime, if indeed lime is a part of it. Its relation to the oxides, bayate, and orientite, indicates that it was deposited essentially contemporaneously with orientite.

Zeolites are present at many openings on the Costa, Manuel, and Vicente claims near Bueycito, but are not conspicuous in several other localities that were examined. The commonest zeolite near Bueycito is stilbite which generally fills veinlets that cut the mineralized tuffs. Analcite in crystals up to 1 cm. in diameter, chabazite in rhombohedrons up to 5 mm. in diameter and laumontite in bundles of lath-shaped crystals, cover drusy cavities at a number of localities. These four zeolites uniformly appear to be deposited later than orientite and the manganese oxides.

Quartz occurs in druses, here and there as doubly terminated dark gray crystals. The color is due to included minute grains of manganese oxide and here, at least, appears to have been deposited contemporaneous with and later than the oxides. Its relation to the zeolites has not been determined. On the other hand, "bayate," a brownish jasper or chalcedony which is made up of minute spherulites and is almost universally abundant near every manganese deposit in Cuba, appears to be earlier than or contemporaneous with the manganese oxides.[7] A clear limpid amorphous mineral that is probably opal is present in some thin sections. It appears to have been deposited after the oxides of manganese and orientite, but its relation to calcite and the zeolites is not clear.

Barite occurs in the deposits as radiating aggregates of thin tabular crystals intimately associated with orientite, and as clusters of tabular crystals in druses in manganese oxides. Most of it appears to have been deposited contemporaneously with orientite.

Glauconite (?) is intimately associated with bayate in most deposits. It forms thin fibrous green films on the borders of the bayate masses generally adjacent to the unaltered tuffs and most remote from the bodies of manganese oxide and orientite. The identification of the mineral near Bueycito is based wholly on the index of refraction (1.61) and the birefringence.

Materials having the same properties and associations was collected by Burchard in several districts in Cuba.[8]

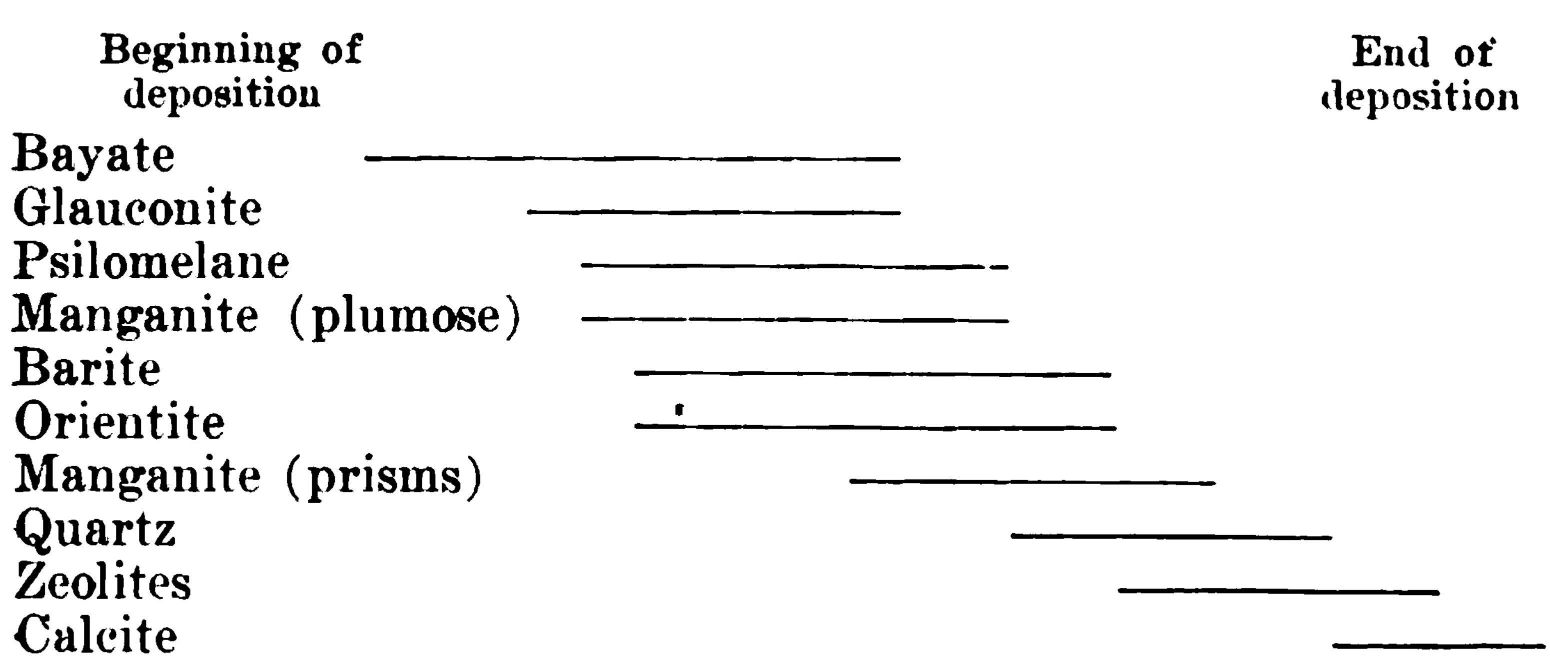
[7] Burchard, E. F., loc. cit., p. 58-60.
[8] Burchard, E. F., loc. cit., p. 89.

Calcite is present in many deposits near Bueycito, and uniformly is the latest mineral. It occurs as short scalenohedrons terminated by flat rhombohedrons which line drusy cavities and commonly rest upon one of the zeolites. Elsewhere it fills the space remaining after the other minerals were deposited (fig. 1).

It should be noted that in the Bueycito region orientite and the other silicates susceptible of decomposition by weathering are uncommonly fresh and that the ordinary products of weathering characteristic of residual deposits, wad, variegated clays, etc., are practically absent. In general the rocks adjacent to the bodies of manganese oxide and orientite are quite fresh. Burchard, however, has described[9] several deposits, such as those near Palmarito, where manganese oxides are imbedded in clays that lie in solution cavities in limestone.

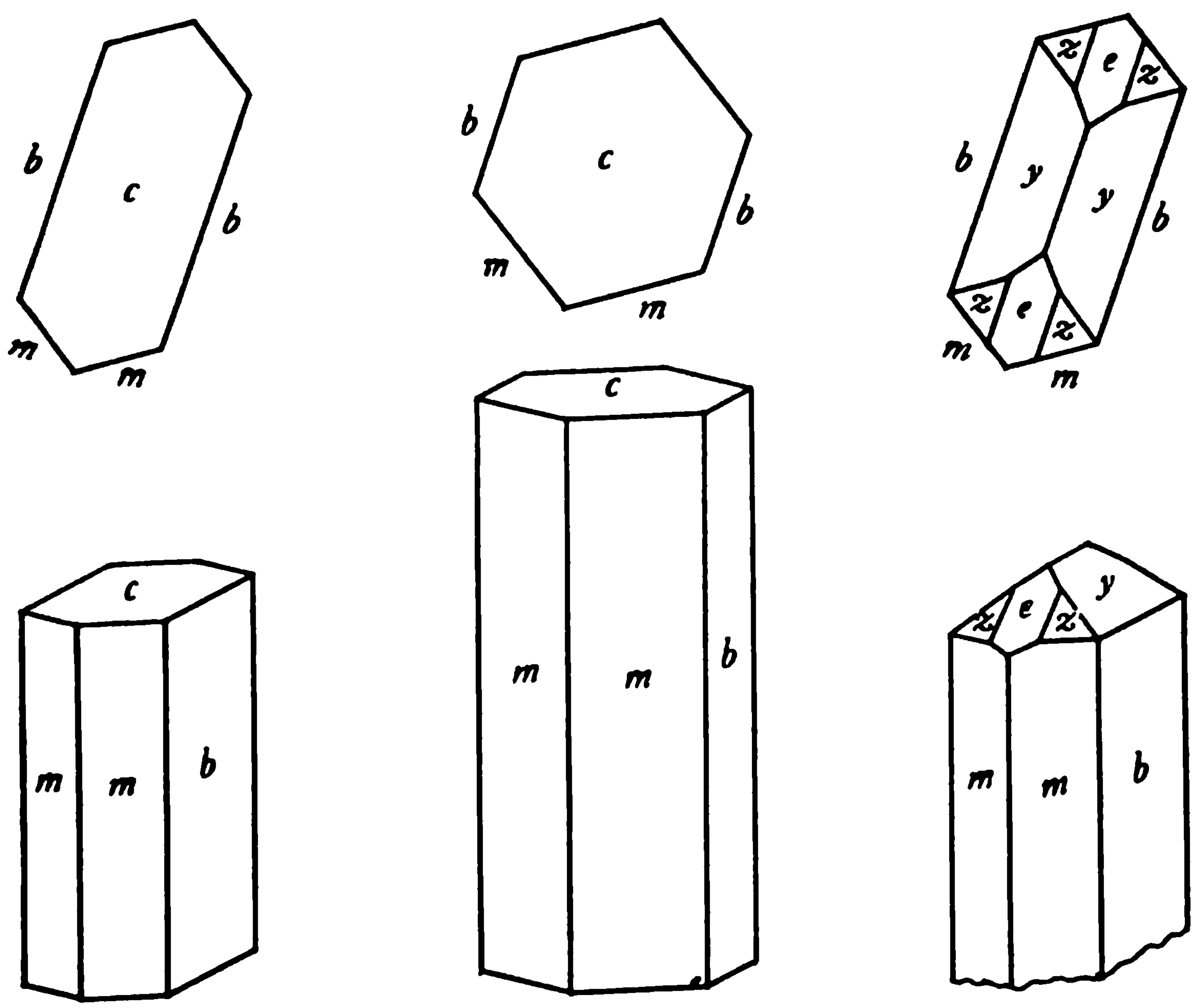
Summary of Paragenesis.—In the Bueycito region, the several minerals that make up the manganese deposits have been deposited by the replacement of latite tuffs. Here and there, in parts of some of the richer deposits, the tuffs have been completely replaced and no traces of the original minerals remain. In some of the poorer deposits however, and on the borders of all of the deposits, replacement has been selective; the fine matrix of the tuffs in general is replaced by oxides of manganese and the glassy fragments and calcareous fossils are replaced by orientite. The feldspars resist replacement in this zone.

From the study of thin sections and polished opaque sections the following tentative order of genesis is indicated:



[9] Burchard, E. F., loc. cit., p. 25.

Genesis.—It is not possible at this time to present all of the geologic data that bear upon the genesis of the deposits in which orientite is persistently present. It may be only briefly stated that the intimate association of the manganese oxides and orientite with zeolites and quartz, apparently without a pronounced interruption of the process of deposition, indicates that the first group have the same mode of origin as that commonly ascribed to the second, *i. e.*, deposition by warm hypogene waters. It should be noted that this is essentially the mode of origin suggested by Spencer in 1902,[10] although the evidence apears to be more conclusive at this time.



A. B. C.

FIG. 5. Orientite from Cuba.

Part II.

Crystallography.—Orientite crystallizes in the orthorhombic system. It occurs as granular masses, as rosettes of radiating prismatic blades, and as distinct crystals making up drusy crusts. The crystals are small, the largest not exceeding 1 mm. in length and the average being very much less than this. There are two principal habits which grade into each other. Crystals of the most

[10] Hayes, C. W., Vaughan, T. W., and Spencer, A. C., loc. cit., p. 63.

common habit are prismatic with the length 1½ to 4 times the diameter. These show only the basal pinacoid *c* (001), the brachypinacoid *b*(010), and the unit prism *m*(110). The prism and brachypinacoid are about equally developed so that the crystals appear very much like hexagonal prisms (fig. 5, B). The second habit has the same simple combination but the crystals are distinctly tabular parallel to the pinacoid *b*(010) with the length 1½ to 2 times the breadth (fig. 5, A). The larger crystals are often composite being made up of smaller individuals in parallel position. The faces of all crystals large enough for goniometric measurement are imperfect, the prism faces being striated horizontally and more or less bulged while the base is usually somewhat concave. The only crystal found which was not terminated by the base alone was very minute and as shown in fig. 5 C was tabular parallel to *b*(010) and was terminated by forms which, by their zonal relations, were identified as *y*(011), *e*(102) and *z*(112). This crystal could not be measured on the goniometer and the only angular value obtained was measured under the microscope. This was the angle *e*(102) : *e*′(102) = 61°00′ or,

$$e\ (102) \quad \phi = 90°00' \quad \rho = 30°00'$$

The value given for the *c* axis, based, as it is, upon this measurement alone, is obviously only an approximation. The mean of 9 good measurements on crystals of the simpler types gave as the angle for the prism:

$$m = (110) \quad \phi = 56°06' \quad \rho = 90°00'$$

or *m*(110) : *m*‴(110) = 67°48′. From the above angles the following constants are derived:

$$a = .6720 \quad p_o = 1.1780 \quad \log.\ p_o = 10.07115$$
$$c = .7916 \quad q_o = .7916 \quad \log.\ p_o = 9.89851$$

These values give the following theoretical angles for the forms observed:

Forms, Goldschmidt Symbols, and calculated angles of orientite

Letter	Miller.	Gdt. symbol	ϕ	ρ
b	010	0 ∞	0°00′	90°00′
c	001	0	0°00′	0°00′
m	110	∞	56°06′	90°00′
e	102	½ 0	90°00′	30°30′
y	011	0 1	0°00′	38°22′
z	112	½	56°06′	35°22′

Physical properties.—Single crystals of orientite are transparent except where clouded by disseminated oxides. The crystalline druses are bright and sparkling and are light brown in color when the crystals are free from impurities. In the majority of specimens, however, the crystals themselves contain more or less finely divided black impurity and consequently range from dark brown to almost black in color. The crystalline-granular massive material is dark brown in color with pitchy to dull luster. The luster of the crystals is more or less resinous. Occasionally they are iridescent to submetallic or metallic in luster due to very thin exterior coatings of a steel-gray manganese oxide. The powder is light hair-brown and the streak slightly darker. The mineral shows a very imperfect cleavage parallel to $m(110)$ and probably also a still less perfect cleavage parallel to $c(001)$. It is brittle with a hardness of 4.5-5. The mean of four closely agreeing determinations of the specific gravity is 3.05.

Optical properties: Orientite is biaxial positive with the optic plane parallel to $c(001)$. The optical orientation is:

$$X = a \qquad Y = c \qquad Z = b$$

Crystals of the tabular or type 2 habit lie on the face of $b(010)$ and yield a symmetrical interference figure indicating that the obtuse bisectrix is perpendicular to this plane or that the acute bisectrix is perpendicular to $a(100)$. Type 1 crystals often rest on a face of $m(110)$ and then yield a figure showing a perfectly centered optic axis indicating that the optic axes coincide with the normals to the prism faces; therefore $2V = 67°$; $2E$ (calculated) $= 156°$. The pleochroism is marked: X, red brown; Y, yellow; Z, brownish yellow. Absorption $X>Z>Y$. The dispersion is pronounced but owing to the large value of 2E the bars of the optic axis are so straight that the direction of curvature is difficult to distinguish. So far as could be determined the dispersion is $\rho<v$. The indices of refraction are high while the birefringence is moderate. The values for the indices of refraction and the birefringence are as follows:

$$\alpha=1.758 \quad \beta\doteq1.776 \quad \gamma=1.795 \quad \gamma-\alpha=.037 \text{ all } \pm1.005$$

Composition and chemical properties.—Crystallized orientite is unattacked by cold dilute hydrochloric acid but is readily soluble in hot hydrochloric acid with evolu-

tion of chlorine and separation of flocculent silica. It is practically insoluble in concentrated nitric acid but is partly decomposed by boiling with moderately concentrated sulphuric acid and yields a rose-purple solution which becomes brown on dilution, precipitating brown manganic hydroxide.

Material for analysis was selected with extreme care as it was necessary to avoid, so far as possible, included calcite and manganese oxides and also those portions of the drusy crusts which bore superficial coatings of oxides or of the colorless transparent opaline material. The best specimens consisted of cellular masses made up of thin ribs coated on both sides with drusy crystals. Such masses were crushed and the purest grains and aggregates of crystals were selected by hand under a high-power binocular microscope. In many cases the thicker ribs have a medial line of gray oxide and the groups of crystals are often grown around a nucleus of opaque steel-gray oxide as shown in the photomicrograph (fig. 1). It was possible to recognize these areas of oxide under the binocular microscope and to avoid them. The selected samples were ground for analysis but, when examined optically, they presented a rather unsatisfactory appearance as many of the grains were more or less dusted with what appeared to be a black opaque pigment of oxide. The dark material appears to be an exceedingly fine dust and many of the clear brown crystals have a central nucleus of the dust-like material, the opaque core locally having exactly the same form as the exterior of the crystal. The samples on which the analyses given in columns 1 and 2 below were made contained more or less of this opaque material in from 10 to 20 per cent of the grains. As treatment with heavy solutions and with an electromagnet failed to effect any further purification of the mineral, the muddy and the transparent grains have practically identical specific gravity and magnetic attractibility. During microscopic examination of sample 2 it was noted that the muddy impurity was practically confined to the larger grains while the smaller grains were mostly clear and transparent. Accordingly the finer material was separated by livigation with water and the product thus obtained showed very little of the opaque impurity. An analysis of this last portion is given in column 3 below. As will be seen, the analyses show but

little variation which can be ascribed to the dust-like material and it seems probable that, despite its conspicuous appearance under the microscope, this is exceedingly tenuous and of practically negligible mass. It is believed that no appreciable amount of extraneous manganese oxide was included in any of the samples analyzed.

The results obtained upon analysis of the three separate samples are given in the following table. Standard analytical methods were used; the state of oxidation of the manganese was determined by collecting, in potassium iodide solution, the chlorine evolved upon solution of the mineral in hydrochloric acid and titrating the liberated iodine with standard sodium thiosulphate solution.

Analyses of crystalline orientite.

Constituent	1	2	3	Average
SiO_2	32.97	31.42	33.05	32.48
Al_2O_3	2.05	1.03	.17	1.08
Fe_2O_3	1.36	1.62	1.70	1.56
MnO	29.93	28.60	31.22	29.92
O	3.39	3.24	3.21	3.27
CaO	22.04	21.90	23.47	22.47
MgO	trace	trace	trace	trace
ZnO	trace	....	....	trace
H_2O — 110°C.	.03	....	.04	.03
H_2O + 110°C.	8.48	....	7.39	7.93
Cl	trace	....	....	trace
Total	100.25		100.25	98.74

The excess of oxygen shown in each analysis indicates that essentially all of the manganese is in the manganic state; the average column of the above table with the excess oxygen united with an equivalent amount of MnO to form Mn_2O_3 yields ratios as follows:

Ratios of orientite.

SiO_2	.5386	53.86	1.02 x 5
Al_2O_3	.0108		
Fe_2O_3	.0098	22.48	1.05 x 2
Mn_2O_3	.2044		
MnO	.0130	41.36	.97 x 4
CaO	.4006		
H_2O	.4402	44.02	1.04 x 4

The formula derived from the final column of ratios is then:

$$4CaO.2\overset{\prime\prime\prime}{Mn}_2O_3.5SiO_2.4H_2O.$$

This may be expressed as a hydrous orthosilicate thus:

$$Ca_4\overset{\prime\prime\prime}{Mn}_4(SiO_4)_5.4H_2O.$$

The water is not given off much below a red heat and in this it behaves like constitutional water and it is perhaps possible to regard it as such. This may be done by making half of the water acid and half basic, the formula then being written:

$$H_4Ca_4(MnOH)_4(SiO_4)_5.$$

The condensed percentages of the average column of analytical figures are compared with the theoretical composition required to satisfy this formula as follows:

		Average per cent.	Theory per cent.
CaO	22.47	23.39	24.56
MnO	92		
Al_2O_3	1.08		
Fe_2O_3	1.56	34.91	34.56
Mn_2O_3	32.27		
SiO_2		32.48	33.00
H_2O		7.93	7.88
Total		98.71	100.00

The agreement is satisfactorily close, especially when the difficulty of securing pure material is considered.

Pyrognostics.—The mineral yields neutral water in the closed tube with or without decrepitation. The roasted and dehydrated material is brownish-black in color with a brownish-black streak and is opaque under the microscope. In the forceps before the blast the mineral fuses readily with pronounced intumescence to a blebby black glass. It reacts for manganese with the fluxes.

Relationships.—A search of the literature has revealed no mineral to which orientite is closely related. The only other mineral which contains manganic manganese in similar ratio is kentrolite which is similar crystallographically and the possibility of including the new mineral in the kentrolite group has been carefully considered. The similarity is shown by the following comparison:

	Kentrolite	*Melanotekite*	*Orientite*
Form	orthorhombic	orthorhombic	orthorhombic
Habit	short prismatic	short prismatic	short prismatic
a	.6334	.6338	.6720
c	.8830	.9127	.7916

Orientite differs from this group chemically by having a higher silica ratio as well as in its content of water. The degree of chemical similarity to the members of the kentrolite group may be shown by comparing the formulas thus:

$4PbO.2Mn_2O_3.4SiO_2$	Kentrolite
$4PbO.2Fe_2O_3.4SiO_2$.	Melanotekite
$4CaO.2Mn_2O_3.5SiO_2.4H_2O$.	Orientite

Setting aside the excess of silica and writing all the water as basic these minerals may be compared as follows:

$Ca_2(Mn(OH)_2)_2Si_2O_7.\frac{1}{2}SiO_2$	Orientite.
$Pb_2(MnO)_2Si_2O_7$.	Kentrolite.

The excess of silica precludes the inclusion of the mineral in this group, however, there being no sufficient evidence for regarding such an amount (5½%) as other than essential. The formulas of the minerals of the kentrolite group have, however, been derived from analyses made upon small amounts of material of doubtful purity and their accuracy has been questioned. It is possible that new analyses of these minerals might show them to be more closely related to orientite.

The amorphous material.—The amorphous material is all very impure from the presence of various included substances, chiefly black opaque grains of manganese oxide. It was so obviously impossible to learn much from analyses made upon this impure material that it was not examined in any great detail. The mineral varies from light to dark brown in the hand specimen, the variation being caused by varying amounts of included impurities. The purest grains are clear dark brown in color, having much the color of the crystalline-granular orientite. The luster is resinous and the mineral greatly resembles common brown opal. The powder and streak are pale brown. The material is very brittle and has a conchoidal fracture. The specific gravity is about 2.5 and the hard-

ness is 2.5. Under the microscope the powder is in part composed of a clear light-brown isotropic material the mean index of refraction of which is 1.55. In selecting material for analysis it was possible to avoid silica which occurs along cracks but the analyzed powder showed a large proportion of black opaque oxide as well as a considerable proportion of a fine-grained crystalline mineral thought to be orientite. The analysis gave the following results:

Analysis of amorphous material.

CaO	4.36
MnO	20.91
Mn_2O_3	21.31
Fe_2O_3 $(+ Al_2O_3)$	4.50
SiO_2	23.76
$H_2O + 110°C.$	8.20
$H_2O - 110°C.$	15.60
Insoluble	1.24
Total	99.88

The material is a typical colloid and the water content is extremely variable, a considerable portion being lost over sulphuric acid in a desiccator. The above analysis may be interpreted as an orientite in which the lime has been replaced largely by manganous oxide. This leaves a considerable excess of both manganous and manganic oxides together with the large excess of loosely held water. If the lime be deducted as orientite and the trivalent bases be set aside, the remaining constituents give the ratios of neotocite. In view of the colloid nature of the substance as well as its manifest impurity it appears best to avoid further discussion of the analysis at this time.

ART. XXXVIII.—*Post-glacial Faulting in the French River District of Ontario;* by WILLIAM HERBERT HOBBS.

In the early fall of 1919 the writer made a canoe journey in the French River district of Ontario, where he had occasion to note an importance of post-glacial faulting quite beyond anything which he had seen described in print. Among the geologists who have given some attention to this subject are Woodworth[1] and Matthew.[2]

The district under consideration is one of very pronounced glacial erosion by the combined processes of

FIG. 1.—Polished surface on gneiss. French river district.

plucking and abrasion. Every shore of the channels and every island is modeled into drumlinoid forms and the glistening surface of the rock betrays no trace of weathering (fig. 1). Rarely is there found sufficient cover for the use of tent-pegs about camp, and the forest trees must often gain their foothold in the crevices of the rock. Planings and scorings, as well as the glorified *roches*

[1] J. B. Woodworth, Post-Glacial Faults of Eastern New York, New York State Museum, Bull. 107, pp. 14-28, 1907.

[2] G. F. Matthew, Movements of the Earth's Crust at St. John, N. B. in Post-Glacial Time, Bull. Nat. Hist. Soc. New Brunswick, no. 12, 1894, pp. 34-42. (See also the author's "Earthquakes," Appleton, 1907, pp. 219-225.)

moutonnées which are everywhere, tell the same tale of the tremendous grinding efficiency of the continental glacier which first advanced and later retreated across this region.

The pattern of the channels whose rectilinear elements are so clearly revealed by the drainage map and to which the writer has already called attention,[3] is reproduced on a smaller scale in the individual zigzags of the canoe routes. Some of the fractures which have exercised the control would appear to be pre-glacial, for the glacial modelling of the surface extends down to and beneath the water surface; but in other cases movement along these

FIG. 2.—Post-glacial fault in gneiss. French river district.

fractures has been subsequent to the retreat of the glacier from the district, and escarpments are found on which no trace of the elsewhere dominant glacial polishing and scoring is to be seen. Such escarpments generally run closely parallel to the stream channels and rise to estimated heights in some instances in excess of one hundred feet. Distinct rifts have also been noticed and in such cases the channel is bordered on opposite banks by parallel escarpments. A fault of this sort is shown in fig. 2 and a larger one lined by high escarpments extends for more than a mile. In such cases I have found

[3] Bull. Geol. Soc. Am., vol. 22, p. 151, fig. 26, 1911.

no evidence of the weathered or eroded dikes to which Bell ascribed the rectilinear channels of this region and of many other parts of Canada, and in connection with which he has assumed such an exceptional amount of weathering and subsequent glacial erosion.[4]

University of Michigan,
February 8, 1921.

[4] Robert Bell, Bull. Geol. Soc. Am., vol. 5, pp. 364-366, 1894.

Art. XXXIX.—*A Note on the Cernaysian Mammal Fauna*; by W. D. Matthew.

M. Teilhard de Chardin is the author of an admirable revision of the Carnivora of the Quercy Phosphorites of France. He has recently been engaged upon a revision of the Cernaysian fauna, the oldest Tertiary mammals of Europe, and has just published[1] a brief note of his preliminary conclusions, especially as to the correlation of the fauna. The following translation of his observations may be of interest to American palæontologists:

"The revision of the Victor Lemoine collections preserved in the Paris Museum, researches in various museums in France and abroad and excavations made at Cernay-les-Reims, have led me to a better understanding of the evolution of the Lower Eocene mammal faunas of Europe.

"1. *Age of the Cernaysian Fauna.* The Cernaysian fauna belongs not at the base nor in the middle (as has sometimes been supposed) but at the extreme summit of the Paleocene. The study of the Multituberculates, the Oxyclænidæ (*Arctocyonides*), the Cheiromyidæ (*Plesiadapis tricuspidens* Gerv.), etc., that it contains, shows that the conglomerate of Cernay (and with it, probably, all our Thanetian) correspond exactly to the 'Tiffany beds' of New Mexico, a formation intercalated between the upper Torrejon and the Wasatch. *Plesiadapis tricuspidens,* notably, may be specifically identical with *Nothodectes gidleyi* Matthew of the Tiffany beds. The Cernaysian fauna differs principally from that of the

[1] Comptes Rendus Acad. Sci. France, 1920, seance de 6 Dec., pp. 1161-2.

Tiffany beds by the dominance of very modernized Condylarthra, *Pleuraspidotherium* and *Orthaspidotherium,* which may be related to the Meniscotheriidæ of Cope. *Meniscotherium* does not appear in America until the Wasatch.

"2. *Distinctness of the Sparnacian fauna.* Although it must be placed at the summit of the Paleocene, the Cernaysian fauna remains absolutely distinct from the Sparnacian fauna. The latter, characterized by the association *Coryphodon-Hyracotherium-Paramys,* and by species of the *Plesiadapis daubrei* group, appear suddenly, as a unit, with the Meudon conglomerate. The same faunal association also appears in the fluviatile Landenian of Belgium (*Coryphodon-Hyracotherium-Paramys*), and in the London Clay of Sheppey (*Hyracotherium Plesiadapis* = *Platychœrops* Charlesworth). It exists, mixed with elements of later geologic age, in the Agéian of Lemoine (*Hyracotherium* = *Lophiodochœrus, Paramys* = *Decticadapis, Plesiadapis*). Typical *Phenacodus* is found in France and in Belgium. In sum, the Sparnacian fauna appears as suddenly in Europe as the Wasatch fauna in America, and like the latter, it is characterized by the arrival of Perissodactyls and Rodents. But while in America undoubted Primates and Artiodactyls are found from the beginning of the Wasatch, these two groups are not recognized in Europe until the beginning of the Cuisian.

"3. *Existence of a Cuisian fauna distinct from the Sparnacian.* Separated from the Sparnacian elements which were improperly associated with it, the Agéian fauna is composed of Primates (*Protoadapis*), of Artiodactyls with very simple upper molars (*Protodichobune* Lem. analogous with *Diacodexis*=*Trigonolestes* Cope of the Wasatch), of Perissodactyls (*Parapachynolophus* Lem.), clearly distinct from *Hyracotherium,* and of Lophiodonts. These forms, obtained at an exact geological level (the Teredina sands), represent the Cuisian fauna properly so-called. This is then characterized by the appearance of Primates and Artiodactyls and by a particular stage in the evolution of the Perissodactyls.

"4. *Persistence up to the Ludian* [Upper Eocene] *of a fauna of Sparnacian and of American affinities.* The study of the Mammalia, especially the ungulates, proves that a separation between Europe and America took

place at the end of the Lower Eocene and that it endured up to the Oligocene. It is therefore more remarkable under these circumstances to encounter in the Quercy Phosphorites (especially at Memerlein, Dep't Lot) a small fauna of clearly American affinities. This fauna, which can be fixed as of Bartonian or Lower Ludian age by the occurrence of the same forms in the stratified sequence (Hordwell, Euzet, Bouxviller), includes, besides a Sparnacian genus *Protoadapis* already noticed by Stehlin, the adaptive Creodont genera *Miacis* and *Viverravus,* Chiromyidæ (two species of *Necrosorex* Filh.), and Tarsiids (*Pseudoloris,* Stehl.), all quite nearly related to *Miacis, Viverravus, Apatemys* and the Anaptomorphids of the American Middle Eocene. So close a resemblance between [these types of] the Bartonian of Europe and the Bridger of America proves that long after the separation of the two continents a common residual fauna, mixed with new elements proper to each region, was able to maintain itself and continued to evolve along parallel lines, on the two sides of the ocean.

"The Tarsiids of the Phosphorites, of which I have at hand unpublished specimens showing the upper dentition and the bones of the face, are remarkable as showing a closer resemblance to the living Tarsier than any known fossil form."

The principal collection of the Cernaysian fauna, including the fossils obtained and described by Lemoine in 1878-1893, and important later collections undescribed, are in the Muséum de Paléontologie in Paris, and Père Teilhard's revision was undertaken at the instance of the Director, Prof. Marcellin Boule. On a recent visit to the Paris Museum the writer had the privilege of examining this unique collection, and was much impressed both with the interest of the fauna and with the admirable thoroughness and insight of Père Teilhard's studies upon it. The Tiffany fauna to which he compares the Cernaysian has been only in small part described, but it appears probable that his conclusions will be confirmed by the more complete comparisons to be made later.

SCIENTIFIC INTELLIGENCE.

I. Geology and Mineralogy.

1. *The Appendages, Anatomy, and Relationships of Trilobites;* by Percy E. Raymond. Mem. Connecticut Acad. Arts and Sci., vol. 7, 169 pages (quarto), 11 pls., 46 text figs., 1920.—The sudden death of Professor C. E. Beecher in 1904 left unfinished his studies of the ventral anatomy of trilobites, and it is fitting that one of his students, Professor Raymond, of Harvard, should take up the work and bring it to a successful conclusion. The splendid memoir which results, dedicated to Beecher and having a portrait of him as its frontispiece, contains many of his drawings and photographs illustrating the ventral anatomy of the trilobites, here reproduced for the first time.

The memoir consists of four parts. In Part I are described in detail the ventral appendages of nine American genera: *Neolenus, Isotelus, Ptychoparia, Kootenia, Ceraurus, Calymene, Acidaspis, Cryptolithus,* and *Triarthrus.* Excellent pen and ink restorations are presented of *Neolenus, Isotelus, Triarthrus, Ceraurus,* and *Cryptolithus.* With the exception of the antennules in all of the genera, and the caudal cerci known only in *Neolenus,* all the appendages are biramous. These rami always consist of endopodites and exopodites, and the author sees no other appendages like those described by Walcott in *Neolenus* and *Calymene.* The inner appendages (endopodites) functioned as locomotory organs, either for crawling, swimming, or burrowing, the particular method varying with the species. Doctor Raymond considers the exopodites to have functioned primarily as gills, and only secondarily as swimming organs, and suggests that where the pygidium is large, it served as a swimming organ. He agrees with Beecher in the latter's homology of the cephalic appendages with those of the higher Crustacea, the first pair of biramous appendages being homologous with the antennæ, and the other three pairs representing the mandibles and the first and second pairs of maxillæ.

In Part II are considered the internal structures and habits of trilobites. Except for the eyes, data are rather scanty. The intestinal cavity is thought to have been enlarged beneath the glabella and thence to have passed straight backward beneath the middle lobe of the test. Muscles, nervous system, various glands, heart, etc., are discussed to the extent the structures are known. The "median ocellus" or "dorsal organ" of the glabella of many trilobites is interpreted as the point of attachment of a ligament supporting the heart. The habits of life are considered with respect to locomotion, food, and feeding, and it is found that in maturity trilobites were adapted to planktonic, nectonic, and benthonic environments, according to species. It is suggested that in the early stages of their racial history the trilobites were carnivorous, but that even before Middle Cam-

brian time some had become vegetable feeders and that in the late Cambrian most of them appear to have become omnivorous. A few may have been mud eaters.

Part III discusses the relations of trilobites to the other groups of the Arthropoda, and the conclusion is reached that the trilobites are the most primitive members of the phylum and either directly or indirectly ancestral to all the other orders. The ancestor of the trilobites is thought to have been a "soft bodied, free swimming, flat, blind or nearly blind animal of few segments," and *Naraoia compacta* Walcott is suggested as the most primitive of all known trilobites and hence closest to the ancestral stock. A diagram showing the interrelationships, time of origin, and duration of the Arthropoda is given in figure 41 on page 150. Among the striking phylogenetic conclusions are: (1) that the insects probably had their origin in the trilobites, though not directly, but through some tracheate stock which was directly ancestral to the diplopods and chilopods as well; (2) that the diplopods, chilopods, and the higher Crustacea had their origin in the trilobites back of the Cambrian; (3) that the arachnids, eurypterids, and horseshoe crabs arose in the xenopods (a new subclass of Crustacea), and that this stock also developed out of the trilobites in pre-Cambrian times; (4) that the copepods had their origin in the most primitive of trilobites (Hypoparia), independently from the rest of the higher Crustacea; (5) that the Arthropoda "constitute a natural monophyletic group," of which the Trilobita are the ancestral, oldest known stock; and (6) that the appendages of all other arthropod lines "could have been derived from those of trilobites."

Part IV gives descriptions of the appendages of individual specimens of *Triarthrus becki* Green and *Cryptolithus tesselatus* Green.

An excellent bibliography and an historical review of the investigations relating to trilobite appendages are other parts of the work. The forty-six text figures serve their purpose well, and there are in addition eleven plates, of which ten show photographs or drawings made by Professor Beecher or under his direction. On Plate 11 is given an excellent restoration of *Ceraurus pleurexanthemus*, drawn by Doctor Elvira Wood.

W. H. Twenhofel.

2. *The Geology of Hardin County, and the Adjoining Part of Pope County;* by Stuart Weller, with the collaboration of Charles Butts, L. W. Currier, and R. D. Salisbury. Illinois Geol. Survey, Bull. **41**, pp. 416, 11 pls., 30 text figs., 1920.—In this very detailed county report are described the Devonian, Mississippian, and Pennsylvanian formations, which together have a thickness of over 3,500 feet. The book is particularly valuable because of the detailed description of the Mississippian sequence. The region has been bowed up into an immense dome, then broken into a complex series of blocks and intruded by dikes, sills, and

plugs that are rich in the ores of fluorspar, lead, and zinc, the distribution, occurrence, and origin of which are discussed by Currier. The general geography is treated by Salisbury.

The most interesting portions are those dealing with structural geology (Part II), stratigraphic geology (Part III), and paleontology (Part VI), all by Weller and Butts. The Mississippian is divided into a "Lower" series embracing the Kinderhook, Osage, Meramec, and Ste. Genevieve, and an "Upper" for the various members of the Chester, but both are regarded as of one period. The well known differences of opinion between Weller and Ulrich regarding the sequence and correlations of the various Chester members are clearly stated by the former. Only the fossils which are more important stratigraphically are described and figured photographically. C. S.

3. *Devonian Floras, a study of the Origin of Cormophyta;* by E. A. Newell Arber. Pp. 100, 47 figs. and portrait. Cambridge (University Press) 1921.—It would be manifestly unfair to a friend who has gone to criticise a work left as a first draft by the author. It seems to the reviewer, however, that the "critical review" of Devonian floras is so incomplete as to be of little value as a work of reference, and that it would have been kinder to Arber's memory to have left at least this part of the work unpublished.

Arber considers that the Devonian floras represent an earlier, which he calls the Psilophyton flora, and a later, which he calls the Archæopteris flora. Psilophyton itself is regarded as identical with the petrified remains described as Rhynia, and these along with Arthrostigma, Pseudosporochnus, Thursophyton, etc., are considered as Thallophytes which, anatomically, stand half way between existing Thallophyta and vascular plants. These are the Procormophytes and are not reduced Cormophytes or in any way related to the existing Psilotales, but represent part of the ancestral stock of the unrelated phylae Sphenopsida, Pteropsida and Lycopsida, or what I would call the Arthrophyta, Pteridophyta and Lepidophyta. That is to say, the Sphenophyllum-Calamite-Equisetum phylum, the Lepidodendron-Sigillaria-Lycopod phylum, and the Fern phylum along with higher derivatives, are of independent origin from an algal ancestry. Arber contends that the modern Psilotales are also of algal origin but at a much later geological period and independently, as also are the Bryophyta. Most botanists will agree to the algal ancestry of the so-called vascular plants as there is really no alternative. That they are as polyphyletic as Arber thought is extremely doubtful, although this is the position taken by Church in his recent speculation on the subject.

Both Arber and Church are influenced by the tradition of primitive oceans on a cooling globe, which may or may not have been true. In any event it should be remembered that the duration of time since the earth first became suitable as an abode for

terrestrial life probably reached as far back beyond the oldest known land flora of the Devonian as the interval that has since elapsed and there would have been ample time to have developed the anatomical features of Rhynia by reduction, as seems to have been the actual case in the Psilotales. Serious doubts as to the primitiveness of these types arise when the Cordaitalean woods of the Devonian, which are ignored by Arber, are considered. The Archæopteris flora is regarded by Arber as truly pteridophytic and ancestral to that of the Lower Carboniferous.

Morphologists will be interested in the unfinished outline of the evolution of the stele sketched in Chapter 7, the stages of which are set forth as—first, a single protoxylem group formed by the simultaneous modification of a set of procambial elements, which took place independently in the main axis and branches: second, the substitution of continuous for purely initial transformation, resulting in protoxylem and xylem: third, the formation of a secondary cambium and secondary wood. E. W. B.

4. *Le Platine et les Gîtes platinifères de l'Oural et du Monde;* LOUIS DUPARC and MARGUERITE-N. TIKONOWITCH. Quarto. 542 pp., 96 figs., 11 pls. and an atlas with 5 maps and 8 pls. 1920.—Professor Duparc with various assistants has been studying the platinum deposits of the Ural Mts. and elsewhere for the past twenty years. The partial results of these researches have been published from time to time in various papers and books. In the present work all this material has been gathered together in an exhaustive monograph.

The study of the geology of the platinum districts shows that the mother-rock of the platinum is primarily dunite and to a much less extent pyroxenite. In the Ural Mts. the platinum-bearing rocks have segregated from the original magma in such a way that the center of the mass is now a dunite which is surrounded by a belt of pyroxenite and the whole enclosed by extensive areas of gabbro. The latter rock is practically free from platinum, however. While the book is chiefly concerned with the deposits of the Ural region a chapter is devoted to platinum occurrences elsewhere. The book includes also chapters on the mining methods, metallurgy and uses of the metal. W. E. F.

5. *Elemente der physikalischen und chemischen Krystallographie;* by PAUL GROTH. Pp. 363, 4 pls., 962 figs. in text and 25 stereoscopic charts. Berlin, 1920.—This is a book which treats the various phases of the subject from the standpoint of the chemist. In the chapter on crystals, for instance, the illustrations are all taken from the products of the chemical laboratory. The book is profusely illustrated, for the most part by small but well reproduced figures. The book would have been considered a notable achievement if published under normal conditions and under the present circumstnaces it becomes doubly remarkable. W. E. F.

6. *Crystallography.* A Series of Nets for the construction of

Models illustrative of the simple Crystalline Forms; by JAMES B. JORDAN. London, 1921 (Thomas Murby and Co.).—This consists of a series of charts giving in outline form figures from which models of various simple crystals may be produced by folding. Considering the difficulty and expense involved in acquiring wooden crystal models at the present time pasteboard models made in this way might prove very useful. W. E. F.

7. *New Mineral Names;* by W. E. FORD (communicated—continued from vol. **49**, pp. 452-453, June 1920):—

Armangite. G. AMINOFF and R. MAUZELIUS. Geol. För. Förh. **42**, 301, 1920. Hexagonal-rhombohedral. $c = 1.3116$. Prismatic habit. H. = 4. G. = 4.23. Poor cleavage || c (0001). Color black. Streak brown. Optically —. Indices very high. Comp.—$Mn_3(AsO_3)_2$. Found in a coarse crystalline mixture of calcite and barite from Långban, Sweden.

Brannerite. F. L. HESS and R. C. WELLS. Jour. Frankl. Inst., **189**, 225, 1920. In rough prismatic crystals. Also granular. Color black with brownish yellow coating due to alteration. Streak, dark greenish brown. Opaque. Conchoidal fracture. H. = 4.5. G. = 4.5–5.4. $n = 2.30$. Radioactive. Comp.—A metatitanate, essentially $(UO,TiO,UO_2)TiO_3$. Found in gold placers in Stanley Basin, Idaho. Named after Dr. John C. Branner.

Cesàrolite. H. BUTTGENBACH and C. GILLET, [Ann. Soc. Geol. Belg.], Amer. Min., **5**, 211, 1920. In cellular masses. Color steel-gray. H. = 4.5. G. = 5.29. Comp.—A manganate of lead, $H_2PbMn_3O_8$. Occurs with galena at Sidi-Amer-ben-Salem, Tunis. Named after Prof. G. Cesàro.

Dixenite. G. FLINK, Geol. För. Förh., **42**, 436, 1920. Hexagonal. As aggregations of thin folia, often radiating and sometimes in globular masses. H. = 3–4. Basal cleavage. Color nearly black but red by transmitted light. Luster resinous to metallic. Uniaxial, +. $n = 1.96$. Comp.—$MnSiO_3.2Mn_2(OH)AsO_3$. Found associated with hematite, dolomite, and serpentine at Långban, Sweden. Named from δι *two* and ξένος *stranger* in allusion to the unusual association of SiO_2 and As_2O_3.

Flagstaffite. F. N. GUILD, Amer. Min., **5**, 159, 1920. Orthorhombic. $a : b : c = 1.2366 : 1 : 0.5957$. In minute prismatic crystals. Colorless and transparent. $n = 1.51$. G. = 1.092. Comp.—$C_{12}H_{24}O_3$. Melts at 100°C. Very soluble in warm alcohol and recrystallizes on cooling. Found in the cracks of buried tree trunks near Flagstaff, Arizona.

Higginsite. CHARLES PALACHE and E. V. SHANNON. Amer. Min., **5**, 155, 1920. Orthorhombic. $a : b : c = 0.6242 : 1 : 0.7940$. In small prismatic crystals with pyramid and dome terminations. H. = 4.5. G. = 4.33. $n = 1.745$. Ax. pl. || (010). Marked pleochroism, X = green, Y = yellow-green, Z = blue-green. Comp.—An arsenate of copper and calcium, $CuCa(OH)AsO_4$. Fusible at 3, coloring the flame at first pale blue and then blue-

green. Soluble in acids. Found at the Higgins Mine, Bisbee, Arizona, associated with manganese oxides.

Hydroclinohumite. Titanhydroclinohumite. F. ZAMBONINI, Bull. Soc. Min., **42**, 250, 1919. The material previously called *titanolivine* from the Ala valley, Piedmont, Italy, is shown to be a titaniferous variety of clinohumite in which the fluorine is almost entirely replaced by hydroxyl. 1.3 per cent of beryllium oxide is also present in the mineral.

Kreuzbergite. H. LAUBMANN and H. STEINMETZ. Zs. Kr., **55**, 441, 1920. Orthorhombic. $a : b : c = 0.3938 : 1 : 0.5621$. Pyramidal. Color white to yellow. Basal cleavage. G. = 2.139. $n = 1.62$. Ax. pl. || $c(001)$. $2V = 90°$ approx. Optically —. Comp.—An aluminium phosphate with Fe, Mn, H_2O. Found in pegmatite associated with other phosphates at the Kreuzberg, Pleystein, Bavaria.

Meta-torbernite I. A. F. ALLIMOND, Min. Mag., **19**, 43, 1920. The first dehydration product, known as meta-torbernite I, is shown to exist in the natural material called torbernite from Gunnislake in Cornwall. G. = 3.68. $\omega = 1.623$. $\epsilon = 1.625$. Comp.—$Cu(UO_2)_2(PO_4)_2.8H_2O$.

Phosphoferrite. H. LAUBMANN and H. STEINMETZ. Zs. Kr., 55, 569, 1920. Crystalline masses. Poor cleavage. Splintery to conchoidal fracture. Greasy luster. Color white with pale yellow or green tints. H. = 3-4. G. = 3.165. Biaxial, +. Comp.—Ferrous phosphate with small amounts of MnO, CaO, MgO, H_2O. In pegmatite at Habendorf, Bavaria.

Phosphophyllite. H. LAUBMANN and H. STEINMETZ. Zs. Kr., **55**, 565, 1920. Monoclinic. $a : b : c = 1.0381 : 1 : 1.7437$. $\beta = 89° 22'$. Tabular parallel to $a(100)$ or prismatic. Twinning on base common. Colorless to pale bluish green. Transparent. Vitreous. Perfect cleavage || $c(001)$, good || $a(100)$ and $b(010)$. H. = 3-4. G. = 3.081. $n = 1.65$. Ax. pl. || $b(010)$. Optically —. $2E = 75°$. Comp.—$3R_3P_2O_8.2Al(OH)SO_4.9H_2O$; R = Fe, Ca, Ba, Mg, K_2,Mn. Associated with triplite in pegmatite at Habendorf, Bavaria.

Plazolite. W. F. FOSHAG. Amer. Min., 5, 183, 1920. Isometric. In minute dodecahedrons. H. = 6.5. G. = 3.13. Colorless to light yellow. Vitreous to almost adamantine luster. $n = 1.71$. Comp.—$3CaO.Al_2O_3.2(SiO_2,CO_2).2H_2O$. Found in an altered pegmatite in the limestone quarry at Crestmore, Cal.

Trigonite. G. FLINK. Geol. För. Förh., **42**, 436, 1920. Monoclinic-clinohedral. $a : b : c = 1.03395 : 1 : 1.65897$. $\beta = 91° 31'$. In small wedge-shaped crystals. H. = 2-3. Cleavage || (010) perfect; less perfect || (101). Color sulphur-yellow to brownish. Subtransparent. Luster vitreous to adamantine. $\alpha = 2.08$. $\gamma = 2.16$. Ax. pl. || (010). Comp.—$Pb_3MnH(AsO_3)_3$. Found at Långban, Sweden, implated on dolomite. Names from τριμωνος *triangle,* in allusion to its crystal shape.

Ultrabasite. V. ROSICKY and J. STERBA. Zs. Kr., **55**, 430-439,

1920. Orthorhombic. $a:b:c=0.988:1:1:1.462$. Columnar habit. Prism zone vertically striated. Color, gray-black, Streak black. H. $\doteq$ 5. G. = 6.026. Comp.—$11Ag_2S.28PbS.2Sb_2S_3.3GeS_2$. Found on specimens collected at Freiberg in 1829 and 1833. Named because of its highly basic character.

Vonsenite. A. S. EAKLE, Amer. Min., **5**, 141, 1920. In prismatic crystals without terminations. Either orthorhombic or monoclinic. $a:b = 0.7558:1$. Color black. Streak brownish black. Brittle. H. = 5. G. = 4.2. Comp.—Similar to ludwigite with a greater amount of ferrous iron; $3(Fe,Mg)O.B_2O_3 + FeO.Fe_2O_3$. Fusible at 3 to a black magnetic globule. Soluble in acids. From Riverside, Cal. Named from its discoverer, M. Vonsen.

Xanthoxenite. H. LAUBMANN and H. STEINMETZ. Zs. Kr., **55**, 579, 1920. Monoclinic. In thin plates. Yellow color. Strongly pleochroic. 2E = 115°, approx. G. = 2.844. Comp. —Essentially a hydrous ferric phosphate with FeO, MnO, CaO, MgO, Al_2O_3. Found with dufrenite, cacoxenite and other phosphates at quartz quarry, Hühnerkobel, Rabenstein, Bavaria. Named from Greek for yellow and because of relation to cacoxenite.

II. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *National Academy of Sciences.*—At the recent meeting of the National Academy (see p. 466) R. A. Millikan was elected foreign secretary to succeed George E. Hale, resigned; also George E. Hale and Raymond Pearl were made members of the Council.

The new members elected are as follows: F. M. Chapman, of the American Museum of Natural History; W. LeRoy Emmet, of the General Electric Company, Schenectady; W. D. Harkins, of the University of Chicago; Ales Hrdlicka, of the U. S. National Museum, Washington; A. E. Kennelly, of Harvard University; W. G. MacCallum, of the Johns Hopkins Medical School; D. C. Miller, of the Case School of Applied Sciences, Cleveland; G. A. Miller, of the University of Illinois; B. L. Robinson, of Harvard University; V. M. Slipher, of the Lowell Observatory, Flagstaff, Arizona; L. B. Stillwell, New York City; D. D. Van Slyke, of the Rockefeller Institute, New York City; T. W. Vaughan, of the U. S. National Museum, Washington; H. S. Washington, of the Geophysical Laboratory, Washington; R. S. Woodworth, of Columbia University.

William Bateson, director of the John Innes Horticultural Institution, Merton Park, Surrey, England; and C. Eijkman, of the University of Utrecht, were elected foreign associates.

2. *The Principles of Immunology;* by HOWARD T. KARSNER and ENRIQUE E. ECKER. Philadelphia. Pp. xvii, 309. (J. B.

Lippincott Company. Price $5.00).—The subject of immunity has as yet only comparatively few years of scientific study to its credit. Much of our knowledge regarding infection and resistance to disease is in a state of flux, the generalizations being modified frequently with the advent of new information from the laboratory and the clinic. At a stage such as this a concise guide to the newest contributions—a readable review which is something more than a compilation of experiments or a series of abstracts—is eminently desirable. This new volume seems to serve well the purpose of introducing beginners in its field to the achievements and problems of immunology which are now-a-days written in a language that only the specially tutored can grasp. The reviewers predict a large usefulness for the book.

L. B. M.

3. *Microbiology:* third edition; edited by CHARLES E. MARSHALL. Pp. xxviii, 1043. Philadelphia (P. Blakiston's Son & Co. Price $4.00 net).—This book represents contributions by 25 well-known workers in the domain of bacteriology and related subjects under the editorship of Director Charles E. Marshall of the Massachusetts Agricultural College. The fact that it has already passed through two earlier editions attests its popularity as a textbook and volume for handy reference. Compilations prepared jointly by many writers are only rarely satisfactory to a critical reviewer. They often lack symmetry in treatment and continuity in argument or exposition. Whatever shortcomings Marshall's Microbiology may have in this respect are counterbalanced by the expert opinions of the various contributors. The range of topics is large, dealing not merely with the morphology of microörganisms, but also with their physiology and the role which they may play in relation to human, animal and plant welfare. L. B. M.

4. *Bibliotheca Zoologica II. Verzeichnis der Schriften ueber Zoologie welche in den periodischen Werken enthalten und vom Jahre 1861-1880 selbständig erschienen sind;* bearbeitet von DR. O. TASCHENBERG. Lieferungen 21 to 23. Leipzig, 1921 (Wilhelm Engelmann).—The nineteenth part of the great work edited by Dr. Taschenberg was issued in 1913 (see this Journal, vol. **35**, pp. 558, 559). Part 20 has been published but has not as yet been received; presumably it was lost in the mails during the early part of the war. The three parts now in hand embrace signatures 755 to 784, or pages 6073 to 6312, all belonging to the supplements of the original work. The second half of the seventh volume includes signatures 745 to 777, pp. 5515 to 6256; it bears the dates 1913 to 1921.

It is gratifying that a work so important to all zoologists and so comprehensive in character should have been carried on to this point and be now approaching completion. The brief introduction of the editor to this seventh volume expresses feelings which must be shared by all loyal workers in zoological science to whatever country they may belong.

5. *Flora of Glacier National Park, Montana;* by PAUL C. STANDLEY. Part 5 of volume **22** of Contributions from the U. S. National Herbarium, pp. 235-438, plates 33-52 and index (U. S. National Museum).—The many visitors to the Glacier National Park will be grateful to the author for making accessible to them this work on the varied flora of the Park.

6. *The Topographical Survey of the United States.*—A very important bill has recently been brought before Congress calling for the completion within twenty years of a general utility topographical survey of the territory of the United States. The bill provides for the utilization of the services and facilities of such agency or agencies of the Government as now exist, or may hereafter be created, and the allotment of funds to them from the appropriation here authorized, or from such appropriation or appropriations as may hereafter be made.

The sum of $37,200,000 is authorized to be appropriated for the purposes named; the amounts available being specifically given for the twenty years from that ending June 30, 1923. It is greatly to be hoped that this bill may be promptly enacted.

7. *Report of the Librarian of Congress,* HERBERT PUTNAM, *for the year ending June 30, 1920.*—Much interesting information is given in this report. The Library contained on the date named upward of 2,831,000 books and pamphlets, in addition to the manuscripts, maps and charts, music and prints. Many important additions of special character, war material and others are enumerated.

8. *The Maine Naturalist: Journal of the Knox Academy of Arts and Sciences on the Fauna, Flora and Geology of Maine.* Vol. I, No. 1. Pp. 1 to 40; six plates. Thomaston, April 25, 1921.—This new periodical, to be issued April and October 1st, at the annual cost of one dollar, will be welcomed by all who know the varied interests of Maine in natural history; it is edited by A. H. Norton of Portland and Prof. A. O. Gross of Brunswick. This first number contains eleven papers.

OBITUARY.

PROFESSOR GEORGE FREDERICK WRIGHT died at his home in Oberlin, Ohio, on April 20 at the age of eighty-three years. He was early interested in glacial phenomena and published many papers upon these subjects. His best known book is his "Ice Age in America and its bearings on the Antiquity of Man" (see (3) vol. **38**, p. 412, 1889 of this Journal; this work went through five editions. Other important books are: "Man and the Glacial Period" (1892); "Asiatic Russia" in two volumes (1902); "Origin and Antiquity of Man" (1912); "Story of My Life and Work" (1916). Professor Wright was an editor of the Bibliotheca Sacra beginning with 1884, and in addition to his glacial studies, he was the author of numerous papers and volumes on various religious subjects. His life was long, active and useful.

INDEX TO VOLUME I.*

* This Index contains the general heads, Botany, Chemistry, Geology, Minerals, Obituary; under each the titles of Articles referring thereto are included.

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